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PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF

PHILADELPHIA

VOLUME XXIV

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PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. XXIV. JANUARY, 1907. No. 1

PAPER NO. 1026.

DIFFERENT METHODS OF PURIFYING WATER.

P. A. MAIGNEN.

Read November 17, 1906.

In the paper presented April 16, 1904, after a visit of the members of the Club to the Lower Roxborough Filter Station, certain advantages were claimed for preliminary filtration as a help to slow sand filtration. In the subsequent operation of the filters those advantages have been demonstrated, as shown by the report of the Bureau of Filtration of Philadelphia for the year 1904 (page 100).

The results of Lower Roxborough are compared with those of Upper Roxborough. Both stations receive the same water, but preliminary filtration is employed at Lower Roxborough and not at Upper Roxborough.

COMPARISON OF WATER FROM THE RIVER AND THE WATER COMING OUT OF THE SAND FILTERS.

	Lower Roxborough (with preliminary filtration).	*Upper Roxborough (no preliminary filtration).*
Maximum reduction, turbidity	100.00	95.65
Maximum reduction, bacteria	99.85	99.81
Minimum reduction, turbidity	81.81	83.33
Minimum reduction, bacteria	98.33	95.70
Average reduction, turbidity	96.02	89.78
Average reduction, bacteria	99.66	98.81

Cost of cleaning filters (page 176):		
Number of runs	26	43
Average cu. yds. of sand scraped per run	120	117.75
Average million gallons filtered per run	123.7	78.3
Average million gallons filtered per acre	233.4	108.9
Cost per million gallons of water to scrape, transport, wash, and restore sand	$1.13	$1.85
Other expenses charged	3.43	3.47
Total cost of maintenance and operation	$4.56	$5.32

Average net output of filtered water:		
Total filtering area	2.65	5.60 acres.
Average daily output	8,430,000	9,530,000 gals.
Average yield per acre per day	3,190,000	1,700,000 gals.
Sedimentation capacity	1½ days	15 days

Typhoid Fever Cases, Rate Per 100,000 Population.

Wards 21 and 22 (Which Receive Filtered Water from Lower and Upper Roxborough)	*City of Philadelphia (Excluding Wards 21 and 22).*
3.51 per 100,000	8.75 per 100,000

Reduction, 59.7 per cent.,—presumably due to the improved quality of the water.

The filtering area of the Lower Roxborough sand filters is a little less than half that of the Upper Roxborough filters, and the net rate of filtration at the former station is nearly twice as high as that of the latter.

The maximum rate of filtration at Lower Roxborough was 5 million gallons and at Upper Roxborough 3 million gallons per acre per day. The difference between these rates and the net results given above arises from the fact that when the slow sand filters are started the rate is at first very low—0.5 million gallons; then it is increased to 1 million gallons and later to 2 million gallons and above. The time during which the filters are out of service for scraping, cleaning, and resanding also helps to account for the difference between the maximum and the net effective rates.

The quality of the filtered water at the Lower Roxborough Station has been somewhat better than that of the Upper Station, notwithstanding the fact that at the latter the sedimentation is ten times greater than at the former. This result it evidently due to the use of preliminary filtration.

Preliminary filtration, first established on a large scale at Lower Roxborough, has come to stay, and will, it is believed, ultimately become part of all municipal filtration systems.

FIG. 1.—LOWER ROXBOROUGH PRELIMINARY FILTER HOUSE.

FIG. 2.—FILTER HOUSE, SOUTH BETHLEHEM, PA.

Preliminary filtration in Philadelphia means a practical economy of something like twelve or fifteen million dollars. If preliminary filtration were not resorted to, it would be necessary to expend at least this amount of money in building additional sand filters large enough to produce, at the old rates, the amount of filtered water required.

The water supply of South Bethlehem, Pa., drawn from the Lehigh River, has been filtered during the last two years by an improved slow sand filter plant designed by the author for four million gallons daily.

The following are the bacterial results:

South Bethlehem Water Supply.

Bacterial Analyses of the Water Made under the Authority of Dr. Henry S. Drinker, President of the Lehigh University.

Samples of	Samples Taken at	B. Coli.	Colonies on Gelatin Plates.
1906			
Jan. 10........	Reservoir.	Present in 1 c.c.	325
	Filter outlet.	Not present.	12
	Tap at University.	Not present.	31
Jan. 17	Reservoir.	Present in 1 c.c.	650
	Filter outlet.	Not present.	2
	Tap at University.	Not present.	27
Jan. 24........	Reservoir.	Present in 1 c.c.	1155
	Filter outlet.	Not present.	5
	Tap at University.	Not present.	53
March 8.......	Reservoir.	Present in 1 c.c.	800
	Filter outlet.	Not present.	15
	Tap at University.	Not present.	32
March 15......	Reservoir.	Present in 1 c.c.	150
	Filter outlet.	Not present.	14
	Tap at University.	Not present.	33
March 22......	Reservoir.	Present in 1 c.c.	160
	Filter outlet.	Not present.	8
	Tap at University.	Not present.	28
April 5........	Reservoir.	Present in 1 c.c.	120
	Filter outlet.	Not present.	2
	Tap at University.	Not present.	16
May 19........	Reservoir.	Present in 1 c.c.	2209
	Filter outlet.	Not present.	9
	Tap at University.	Not present.	41
June 6........	Reservoir.	Present in 1 c.c.	275
	Filter outlet.	Not present.	0
	Tap at University.	Not present.	20
July 16........	Reservoir.	Present in 1 c.c.	750
	Filter outlet.	Not present.	3

The term "reservoir" here refers to a storage basin in which the water remains four or five days on its way from the river to the filter.

The "tap at the University" at which the sample was drawn is near one of the dead ends of the water-pipe system. The difference between the water drawn from the "filter outlet" and from the "tap" is explained by the fact that the filtered water passes through an open filtered water basin holding two days' supply.

The above bacterial analyses were made by Mr. F. W. Green, bacteriologist of the Little Falls (N. J.) filter plant. The samples were taken by one of the students of the University and carried by train to Little Falls once a week.

These analyses show three points of interest:

1. The very low count of bacteria in the filtered water.

2. The presence of the Bacillus coli in all the samples of raw water and its absence in all the samples of filtered water.

3. The small increase in the number of bacteria found in the filtered water drawn at the University.

The vital record is as satisfactory as the bacterial record.

NUMBER OF CASES AND DEATHS OF TYPHOID AND ENTERIC FEVER AT SOUTH BETHLEHEM, PA.

	1903.		1904.		1905.		1906.	
	Cases.	Deaths.	Cases.	Deaths.	Cases.	Deaths.	Cases.	Deaths.
Jan	17	4	5	5	1	0	1	0
Feb.	6	14	6	5	1	0	2	2
March	68	7	2	5	0	0	0	0
April	66	12	8	2	0	0	1	1
	157	37	21	17	2	0	4	3

TOTALS.

1903–1904. Before the filter plant was installed.*		1905–1906. After the filter plant was installed.	
Cases.	Deaths.	Cases.	Deaths.
178	54	6	3

The South Bethlehem filter plant consists of six units of scrubbers or preliminary filters, 16 feet wide, 38 feet long, 6 feet deep, and six units of final filters 16 feet wide, 152 feet long, 6 feet deep. The water from the influent gullet enters the bottom of the scrubbers through

* The filter plant was placed in operation in November, 1904.

8-inch valves (regulated from the floor over the gullet) and it rises upwardly through the scrubbing materials within 6 inches or 8 inches of the top of the side division walls and flows naturally to the filter beds, which are on the same line, and are only separated from the scrubbers by a dwarf wall. When in normal operation, the level of the water on the scrubbers and on the filters is the same, and there is practically no motion on the surface.

In the final filters the water flows downward, in the usual way, through the filtering materials, and comes out into the effluent gallery, which is

Fig. 3.—Interior View of the South Bethlehem Filter Plant.

six feet deep, through 8-inch valves which are always submerged in water. Provision is made at the end of each filtered water outlet for wasting the first filtered water through a 6-inch valve, attached to a pipe connected with the different filter units, and allowing also back filling with filtered water.

The division and end walls, as well as the floors of the scrubbers and final filters, are constructed of concrete reinforced throughout with half-inch square iron bars.

Over the filtered water gallery is a reinforced concrete floor through

which the stems of the effluent valves and re-wash valves pass. These stems are supported by indicator stands, which help to regulate the flow of filtered water. This space may be called the gate chamber. There is plenty of room for the manipulation of the valves, the reading of the loss of head gauges and the sampling of each filter unit.

One of the features of the South Bethlehem plant is the cleaning operation. A yellow pine coping is laid on the division walls and flat steel rails are set thereon. A crane travels on these rails and an

Fig. 4.—Valve Gallery, South Bethlehem Filter Plant.

arrangement is made for the transfer of the crane from one bed to the other.

The crane is used for the following purposes:

1. A platform attached to the crane is lowered close to the sand-bed for the collection of the dirty sand and it is raised for transfer from one filter unit to the other. The man who scrapes the sand stands on the platform, and when the platform is loaded, the crane is pushed toward the sand washer by men walking on the division walls, so that at no time have the men to set foot on the sand-bed itself. The same device is used to receive the clean sand and distribute it over the bed.

2. The crane and platform are also used to level or plane the sand layer after it is replaced on the bed.

3. A trough erected on the crane is used for the distribution of the artificial filtering membrane.

The sand washer used at South Bethlehem was designed by the author and constructed by the Link Belt Co. It consists of four bucket elevators with suitable framework, shafting, countershafting, and a trough. It is operated with an electro-motor which is also used for

Fig. 5.—Crane and Platform to Receive and Carry the Dirty Sand to the Washing Apparatus, to Convey the Clean Sand Back to the Bed and to Plane the Surface after Resanding; South Bethleham Filter Plant.

the sponge-washing machinery. The sand-washing machine and the sponge-washing machine are erected on platforms which are moved on the "I" beams of the scrubber close to the filter in process of cleaning. The crane and platform bring the dirty sand to the washer, it is shoveled from the platform into a boot not more than two feet high, where it is taken up by the first elevator. It is raised some nine feet in the air and then made to drop with a certain force into the water of the trough below; the sand is taken up again by the second elevator, raised and

dropped in the water as before; it is lifted a third time and again thrown in the water; the fourth and last time it is raised from the washing trough and falls in a chute which leads the clean sand to the traveling crane for distribution on the bed. In this process each particle of sand comes in direct contact, more or less violent, with the water which it strikes; it is freed from mud by the force of impact. The sand is handled in very small quantities at a time, is not subject to the law of currents, and never forms any stratification.

The wash water enters in the trough from the far end which receives

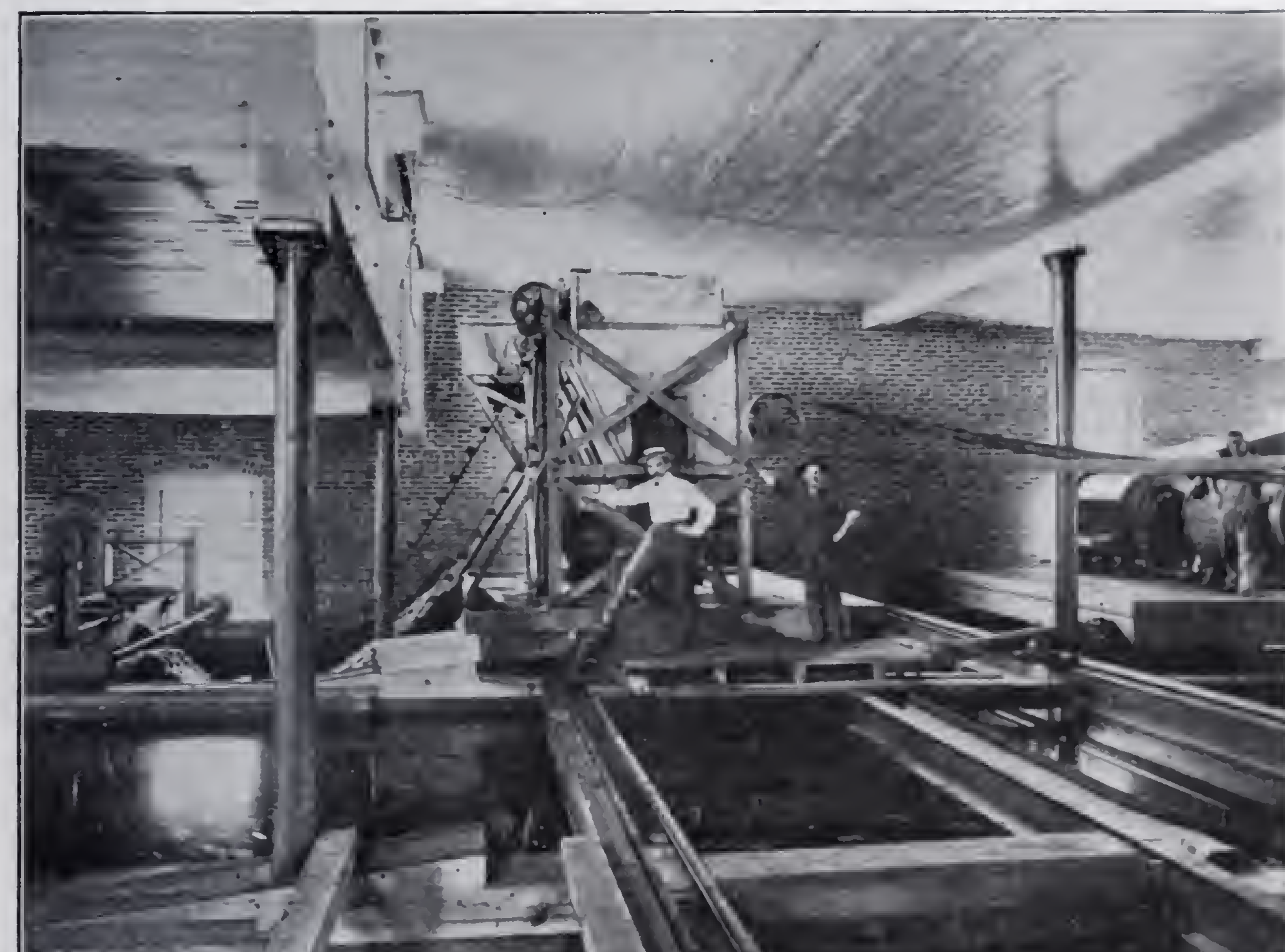


FIG. 6.—SAND WASHER, SOUTH BETHLEHEM FILTER PLANT.

the clean sand and goes out at the near end which receives the dirty sand. The flow is regulated so as not to carry away any of the fine sand.

The following are some of the advantages of this new system:

1. Very little water is required, it need not be filtered water, nor has it to be under pressure.

2. The sand is washed as soon as scraped without remaining in heaps, in courts, exposed to wind, rain, frost, dust, etc.

3. The sand being washed fresh, the mud comes off easily, and being

replaced on the bed as soon as washed, the filtering layer is always of the same thickness.

4. The sand is at no time stratified, as is the case with the ordinary methods of washing.

5. Nor is there at any time any waste or separation of the finer particles of sand, which are absolutely necessary to produce good filtration. By the ordinary system of washing sand, there is considerable separation of the different sizes of particles, according to their specific gravity, and much waste of the finest particles; this renders the efficiency of the filter less and less after each cleaning. With the system inaugurated at South Bethlehem, the physical condition of the sand is always the same.

Among the novel features of the South Bethlehem filter plant as a slow sand filter are:

1. Light and well ventilated filter house.
2. Narrow filter beds and comparatively small units. One-eighteenth of an acre instead of the usual large units of half, three-quarter, or whole acre.
3. Shallow layer of water over the sand-bed showing the possibility of reducing the height of the filter walls to a minimum.
4. Cleaning without trampling on the sand.
5. Washing the sand without losing the fine particles or separating it in different grades.
6. Avoiding sand courts with the waste and pollution resulting from exposure.
7. High speed of filtration—from six to nine million gallons per acre, per day, right from the start.
8. Long runs of three months or móre without scraping.
9. Facilities for distributing and removing the filtering materials, and forming the artificial membrane.
10. Compactness, simplicity, and easy control of the whole plant.
11. No constant labor of any kind, the attendant hitherto in charge of the reservoirs attends to the filters. When a cleaning operation is necessary, it is carried on by the ordinary staff of the water compny.
12. The mechanical power required for all the washing operations is supplied by a 5 H. P. electrical motor.

At the St. Louis Convention of the American Society of Civil Engineers, in 1904, the author was asked if he had any information as to the effect of storing filtered water in open reservoirs, and he had to acknowledge, at the time, that he had none. Now he has had two years' experience

at Bethlehem, Pa., nine months at Lancaster, Pa., and nearly two two years at Kittanning, Pa. In no case has he found the filtered water seriously affected by exposure.

No doubt some germs fall into open reservoirs with the dust of the air, with the leaves, and in various other ways, but they do not seem to multiply to any great extent. Is it because the filtered water does not contain more than a trace of organic matter? Is it because the sunlight checks their growth or kills the adult bacteria? We do not know.

The very small increase in the number of bacteria found in the water drawn from the town pipes as compared with those in the water collected direct from the filters, is very interesting, particularly when we think of the precautions considered necessary in collecting and transporting samples of water for bacterial examination.

With the present information the author sees no objection to the storage of filtered water in open reservoirs, provided, of course, care be taken to prevent dirt of every description, dogs, and would-be suicides getting into them. It would be very much better to have a large open reservoir able to compensate fully for the difference in the consumption at different hours of the day and night, without changing the rates of filtration, than to have a small covered reservoir with which it would be necessary to change the rate of filtration several times a day to respond to the ever varying demand of consumption.

The city of Lancaster, Pa., is supplied with water drawn from the Conestoga River. It is filtered by an improved slow sand filter plant designed by the writer and is intended to purify nine million gallons of water daily. It was placed in operation in April, 1906. The bacterial and turbidity record is given on page 13.

The samples were brought from Lancaster to Philadelphia and were planted from six to twenty-four hours after being drawn. They were read forty-eight or seventy-two hours after planting.

Fig. 7 shows the general view of the Lancaster filter plant in use before the roof was put on. This filter plant has several features of special interest:

I. There is no storage or settling reservoir. The water is pumped direct from the river to the filters all the time, day and night, whether it be roily or not.

There were last summer seventy-five thunder-storms, and after each storm the river rose, and much loam, clay, and vegetable detritus made the water extremely muddy. To meet this special condition the

writer designed and installed, in addition to the improved slow sand filter, a system of chemical purification along the lines of his water softening system, which is largely used in England for the purification of hard (drinking) water.

In this system the reagents are used in a dry powdered form. The powder is placed in hoppers from which blades expel it through sliding doors opened more or less according to the requirements of the water. The incoming water is made to impinge upon an undershot water

FIG. 7.—LANCASTER FILTER PLANT IN USE BEFORE BEING COVERED.

wheel of the Poncelot type, and the force thus obtained is sufficient not only to expel the powder from the hoppers but also to stir up the water in which the powder falls, so that there is a thorough mixing of the reagents with the water.

The quantity of powder is proportioned to the quantity of incoming water. If the water comes to the wheel fast, the hoppers deliver the powder fast; if the water comes slowly, the powder is supplied slowly to the water; and if there is a complete stop of the water, there is also a complete stop in the supply of the powder.

The success of this feature is absolute. More than four hundred installations have been made and maintained in England for many years, for softening the water coming into houses, mansions, and public institutions, and there has never been a failure. Water-softening processes in which the reagents are used in a liquid form have all failed more or less at some time or other because of the practical impossibility of securing regularity in the proportionate feed of the reagents.

City of Lancaster Water Supply.

Bacterial and Turbidity Record of the Filter Plant. Analyses made by Dr. W. J. Dugan, Bacteriologist.

Date.	Bacteria.		Per Cent. Removed.	Turbidity Effluent. Parts per Million.
	Raw Water.	Gen. Effluent.		
1906.				
April 16......	3,800	69	98.18	3
18......	5,400	66	98.96	1
24......	4,300	32	99.30	1
26......	3,200	26	99.25	1
May 8......	5,300	69	97.7	0.0
20......	7,600	69	98.94	0.5
24......	5,700	86	98.50	..
June 1......	9,800	78	99.18	1
6......	10,200	80	99.22	0.0
8......	3,600	65	98.47	1
11......	4,100	36	99.11	0.5
15......	3,300	25	99.24	0.5
21......	11,600	90	99.20	0.5
26	8,040	63	99.22	0.0
28	11,760	75	99.36	..
July 5	5,630	23	99.59	0.5
12......	6,970	59	99.15	0.0
18......	12,300	93	99.24	1
19......	8,970	61	99.32	0.5
24......	18,400	59	99.68	0.5
26......	12,200	..	..	0.0
Aug. 1......	5,690	10	99.82	0.0
3......	4,380	40	99.09	0.5
7......	5,360	12	99.64	0.5
9......	8,390	79	99.07	..
14......	4,670	14	99.70	0.5
16......	8,690	60	99.31	0.0
21......	6,280	17	99.73	0.0
24......	16,300	46	99.72	0.0
28......	8,360	28	99.81	0.0
30......	7,630	21	99.72	0.0
Sept. 5......	5,600	21	99.63	0.0
6......	6,180	31	99.34	..
10......	3,300	15	99.55	..
17......	6,780	43	99.37	0.0

After receiving the desired quantity of reagents (at Lancaster) the water passes into a circular tank 50 feet in diameter, 10 feet deep, with three concentric baffle-walls which help to further agitate the water, then through another tank of the same size with one baffle wall. The water settles in this latter tank and it finally passes into two other tanks of the same size but at the bottom of which there is a series of layers of coarse scrubbing materials, stone, coke, and sponge. After leaving these two tanks the water is in a very good state of preparedness for filtration.

At first the reagents used at Lancaster were principally lime and soda,

FIG. 8.—INTERIOR VIEW OF THE LANCASTER FILTER PLANT.

with a view of softening the water, but as it was considered desirable not to change the chemical character of the water in any way whatsoever, sulphate of alumina and soda carbonate are now used. These two reagents neutralize each other. They simply coagulate the fine suspended matter without making the water harder or softer and without leaving anything objectionable in it. The water is never more acid nor more alkaline after treatment than before.

This process is, of course, more expensive than that in which sulphate of alumina or alum alone is used, but it is more satisfactory. It is

folly to trifle with the health of the people for economy's sake; we must purify the water and not make it worse (as is the case when sulphate of alumina or alum alone is used).

The water thus prepared now goes to the filter system proper, which is composed of fifteen scrubbers (or preliminary filter units) 35 feet long, 16 feet wide, 6 feet deep, and fifteen final slow sand filters, 140 feet long, 16 feet wide, 6 feet deep. Each filter unit is therefore 2240 square feet, or about $\frac{1}{20}$ acre.

The materials used in the scrubbers, beginning from the bottom are:

1. A 9-inch layer of 3-inch pebble stones.
2. A 9-inch layer of coke, "stove" size.
3. Twenty-four inches of space is occupied by four rows of slates placed at a slight angle upwardly, each row in a contrary direction, so that the water in its upward flow is compelled to take a circuitous or spiral course. The space between the slates is filled with coke "nut" size.
4. An 18-inch layer of sponge, held down by cedar slats, yellow pine stringers, wood blocks, and steel "I" beams fastened on the walls.

The drainage system in the sand-beds or final filters is similar to that of the scrubbers. It consists of convex slabs made of concrete, with openings at the base. These slabs are laid in the center of the bed whose floor is dished. A perfect drainage is thus secured and no stagnant water can remain in any part of the filter bed.

The materials used in the final filters, beginning from the bottom are:

1. Eighteen inches of gravel, graded from 3 inches to $\frac{3}{16}$ inch.
2. Two feet of filter sand.

II. The second feature of interest—employed also at the South Bethlehem plant—is the formation of an artificial filtering membrane on the surface of the sand layer. It has been said that a sand filter is not good unless it has on the surface what has been called an "algean jelly," a "Schmutzdecke" (mud blanket), or a "biological" filtering membrane. There is in this statement a grain of truth and a mountain of fiction. The grain of truth is that the accumulation of particles of very fine suspended matter, organic and inorganic, on and between the grains of sand, fills the voids and increases the density of the sand layer. In other words it makes a physically finer filter.

The idea concerning the "algean jelly" had its origin in Europe, where the filters are usually uncovered and in which algæ grow on the sand under the influence of sunlight.

Algæ do not grow in covered filters and if their presence were neces-

sary to good filtration their absence in covered filters would lead to bad results, which is not the case.

The existence of a natural "Schmutzdecke" coincides with the better physical condition of the sand layer, the improvement in the filtrate is not proportionate to the thickness of the mud. It may be said, however, that the increase in mud, as we shall see later on, does not tend to make the filter worse; if anything it makes it better.

The promoters of the "biological" idea would have us believe that there are accumulated on the sand bed cannibal-like bacteria whose propensity is to eat their weaker brethren. This is pure romance!

Fig. 9.—Lancaster Filter Plant and Pure Water Reservoir.

The fact, however, remains that the natural or artificial deposition of fine particles of suspended matter on the sand is a decided advantage. In the operation of the plain slow sand filters in which there is nothing but a natural or mud membrane, the filters are started first at 0.5 million gallons per acre per day and kept at this rate for several days, then the speed is increased to 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and sometimes 3 million gallons per acre per day!

It occurred to the writer that instead of trusting to the slowly formed

and delicate natural "Schmutzdecke" it would be better to deposit on the sand layer at the beginning of the operation a film of finely divided inorganic matter. This has been done with success at South Bethlehem and Lancaster and the filters are started at full rates—6, 8, or 9 million gallons per acre per day.

Some years ago the writer advocated using asbestos fiber for the artificial filtering membrane. He used it at South Bethlehem, but has found that equally good results could be obtained with fine charcoal

Fig. 10.—Lancaster Filters, before being Covered. Algæ Growth in the Near Bed, no Algæ in the Far Bed.

and fine coke. Coke is that which is now used at South Bethlehem and Lancaster.

After passing through the filtering system the purified water goes into an open pure water reservoir built of reinforced concrete, 200 feet long, 100 feet wide, 12 feet deep, having a total capacity of about 1,500,000 gallons.

The effluent pipes are so arranged that the reservoir can be emptied at any time for cleaning. When this is done the filtered water goes directly from the filters to the high duty pumps.

There is quite a difference of opinion among filtration men as to the best depth of underdraining materials. In London, for instance, 30 inches is the accepted thickness; in Berlin 33 inches. Some engineers in this country think 12 inches enough. The author prefers 18 inches.

Fig. 10 shows a curious phenomenon well worthy of attention. One of the filter units presents a spotless sheet of water. In the other are to be seen dark spots on the surface of the water and against the filter wall. This represents green algæ. Out of fourteen filter beds in use at the time seven had this growth, and the other seven had none whatever. The applied water was the same; the exposure the same; the period of time in use the same. The only difference between the two was that in the filters which had no algæ the sand was covered by a thin coating of powdered coke, while in the other the sand was bare, and it was on the bare sand that the algæ took root and grew in a few days so as to cover the whole surface of the beds like a diminutive forest of pine trees. In some of the beds in which the coke was placed some parts of the black filtering membrane were removed so as to expose the sand, and immediately within a day or two algæ grew in those parts.

We state the fact but cannot offer any explanation. Had the black color of the coke any specific rôle in thwarting the fertilizing influence of the sun's rays, or was it the coke itself which was incapable of supporting vegetable life? In considering the latter supposition we should bear in mind that there were only 300 pounds of very finely divided coke distributed over 2240 square feet of surface. The layer was certainly not more than $\frac{1}{32}$ inch thick.

The theory of the black color would appear to be supported by an observation made at South Bethlehem. The pure water basin is lined with riprap stones. These stones were habitually black, owing to the soot of the locomotives (of the Lehigh Railway) falling into the reservoir. No trouble had ever been experienced before, but this summer, in order to show off the transparency of the filtered water, the superintendent of the filter plant had the idea of whitewashing the stones some 4 feet below the flow line, and sure enough there soon came a very luxuriant growth of algæ on the white stones. Since the stones have become black again the algæ have not made their appearance.

Sand filtration is supposed to be a natural process—an imitation of nature, but it is not so. Nature's sand is never disturbed; it is never taken out and washed; no dirt ever comes in contact with it. When the water gets to the sand in nature it has long before been clarified or

scrubbed by leaves, roots, débris, loam, gravel, etc. Nature's sand is not confined between walls. It has thousands of acres to do its work.

When any one says that a process is like that of nature, no further explanation or proof is asked. "Of course if it is natural it must be good!" But what is known as a plain slow sand filter has very little in common with nature. It may even be said that there is very little engineering science or art about it.

Dr. Kemna, of Antwerp, describes a plain slow sand filter as follows: "A heap of sand—water is put on the top and extracted from underneath. It is worked by a foreman who knows, of course, how much water he pumps on the filters but who cannot always tell how much each particular filter is doing, its speed, etc. Generally the filters are left to settle that between themselves."

Referring to certain undesirable features in certain plain slow sand filter plants, a young friend of the writer described the system as "a lot of sand in water."

In some cases the sand is not compact enough to make a good strainer. It behaves somewhat like quicksand, offering practically no resistance to the flow of the water. The sand itself may be too coarse or too uniform—that is, not containing enough fine particles to make up a fine screen—or again it may have fissures, breaks, or free passages. These occur particularly along the retaining walls or pillars, so that sometimes the filtering operation is defective.

It is time that students of the art of filtration should cease to merely copy what has been done abroad. They know nothing of the secret failures of these foreign plants; they know only the good that is said of them in books. It is time that they should make some original study as to how *best* to do the work and not how cheaply.

The South Bethlehem and Lancaster plants are object lessons. The members of this Club will be heartily welcomed if they visit them. They will be given full information concerning every detail of construction and operation. They will see new systems of washing the sand in the bed and out of the bed, new ways of scraping and planing the sand, methods of washing the sponge and coke, and many other new features.

Mechanical Filters.

Mechanical filtration is carried on in tanks seldom larger than 20 feet in diameter; sulphate of alumina is added to the water, the small particles of sediment are coagulated and aggregated into comparatively

coarse particles which are easily arrested by coarse sand, and thus it is that very high rates of filtration, from 80 to 120 million gallons per acre per day, are obtained.

Filters do not clog according to the quantity of water which goes through them, but according to the quantity of suspended matter floating in the water. The so-called mechanical or rapid filters must be cleaned more often than the slow sand filters. The cleaning operation is ordinarily done two or three times a day, and, when the water is very bad, every few hours.

This is done by introducing water under pressure below the sand layer and agitating the sand mechanically with rakes (hence the name mechanical filtration), or by blowing air backward through the sand layer. In other words, the sand is agitated in the tank itself, and the impurities are supposed to be removed by the overflowing wash water.

The hygienic results are not always satisfactory. Mechanical filters have been installed in many small cities because the rate of filtration is so high that the size of the plant is comparatively small and proportionately cheap in first cost; but the cost of operation and maintenance is much greater than that of slow sand filters.

The principal defects of this system are:

1. The necessity for constant care and attention day and night to adjust the chemicals to the varying conditions of the water and to attend to the cleaning operation.
2. The cost of chemicals.
3. The increased amount of incrustating constituents in the water.
4. The frequent disturbance of the sand for cleaning—the worst of all.

Dr. Med. Karl Schreiber, of Berlin, in a report on mechanical filtration, considers that "the effluent may be turned to use after half an hour," and he adds: "At times of epidemics, when the raw water is suspected of being infected, it might be well to extend this period to one hour after the commencement of the run."

The advice given by some engineers to the effect that this first water should not be wasted would thus appear to be unwise. They say "the small quantity of impurities coming from one unit out of many would not lower the general efficiency to any very great extent." It may be so, but the author would not like to be a party to such a saving!

The following table shows the work done by mechanical filters immediately after cleaning, and the necessity of wasting the filtered water during the first half-hour of operation:

Date.	*Time.*	*Bacteria in Raw Water Per c.c.*		*Bacteria in Filtered Water Per c.c.*
Nov. 10,	10 A.M.	900	(immediately before washing)	116
	10.50 "	"	(filtering started at 10.40)	1900
	11.50 "	"		3200
	11.20 "	"		510
	11.40 "	"		36
	11.50 "	"		80
	3.30 P.M.	"		42
	4.40 "	"		4800
	6 "	"		22
	Stopped for washing.			
Nov. 15,	11.40 A.M.	5200	(filtering started)	34000
	11.45 "	"		30000
	11.50 "	"		6400
	12 M.	"		1540
	12.5 P.M.	"		895
	12.10 "	"		248
	2.35 "	"		52
	4.00 "	"		38
	4.50 "	"		42
	Stopped for washing.			

Domestic Water Supply.

Are domestic filters a "delusion and a snare" or are they desirable utensils?

The question cannot be allowed to remain in doubt. If they are bad they should be condemned and thrown out of existence altogether. If they are good they should be used and cherished. The fact that a filter is small or large does not make it either good or bad. If there are good big filters, why should there not be good small filters?

Let us study a few of the principles which obtain in the art of filtration as now practised. We may perhaps find out whether there can be any good filters and whether it is possible to distinguish between good, bad, and indifferent filters.

The United States Patent Office classes water filters in two categories:

1. Porous wall filters.
2. Granular bed filters.

Porous Wall Filters.

The most representative specimen of this kind of filter is that made of unglazed porcelain. The pores or channels through which the water has to pass are "fixed" or "rigid." There is no "give and take," as in the loose material of granular beds. If the bacteria or their spores pass the surface openings of these fixed channels there is nothing be-

yond to prevent them passing or growing right through the thin walls. In fact, this has been found to be the case.

M. Armand Gautier ("Encyclopédie d'Hygiène," Paris, 1890), says: "The colonies (of bacteria), at first retained on the surface, grow in and through the pores of the porcelain. . . . This has been confirmed by MM. Gallipe and Villejean."

The "Lyon Médical" (July 15, 1888) says: "The microbes that have succeeded in going through (the pores of the porcelain) grow therein. . . . Unless we tested daily the 'candles' we would not dare to use the water for washing wounds."

M. Lacour ("Revue d'Hygiène," June 20, 1892) says: "After a year's experience . . . the following is the average result:

Filtered water of the first day......	Sterile.
Filtered water of the second day...	Sterile.
Filtered water of the third day.....	Some germs similar to those in the applied water.
Filtered water of the fourth day...	Colonies in increased number.
Filtered water of the fifth day......	Quantity three, four, five, and six times greater than those of the unfiltered water."

M. Miquel (Report to the Paris Municipal Council, Dec. 3, 1892): "The bacteria may traverse the porcelain filter by multiplying in the pores of the filtering material and grow through in a more or less long period of time."

Dr. Chaltin ("Archives Medicales Belges," May, 1894)—summary of experiments:

First day	4 colonies.
Third day....................................	130 colonies.
Sixth day....................................	460 colonies.
Eighth day....................................	780 colonies.
Tenth day	1600 colonies.
The unfiltered water contained.....................	50 colonies.

Dr. Odo Budwig (Paris Congress of Hygiene): "Unfiltered water containing 200 or 300 colonies comes out of porcelain filters with 60,000 or 70,000."

The "Revue Scientifique," Paris (July 13, 1889): "The porcelain filter which, the first days that follow its sterilization, gives water without microbes, gets soon infected, and allows bacteria to pass. It may be a very good laboratory filter, where apparatus for sterilizing is always at hand, and where 'candles' may be at any moment sterilized by superheated steam; but in houses, as a private hygienic instrument, it is a detestable filter.

"It is evident that persons who have got one fixed up in their kitchen or pantry will not get it down every week to replace the 'candle' by a new one or by one freshly sterilized; then, after a few days, the water that such persons drink is, so far as microbes are concerned, not better than that of those who have no filter at all. The danger is all the greater that, on the faith of the assertions of the authors and of the prospectus, such persons as use it have perfect confidence in it . . . This must be said to the public—allowing it to be misled on this subject would deserve to be severely judged."

The conclusion to be drawn from these quotations is that "porous wall" filters must be cleaned and sterilized by heat very often.

Granular Bed Filters.

The best type of "granular" bed filters is that known as "the slow sand filter" used for the purification of city water supplies. In a well constructed and carefully operated slow sand filter the bacteria are retained, with the particles of inert matter, in the voids between the grains, mostly at the surface of the sand layer.

These voids may be compared to cells. Some of the bacteria which fail to remain in the upper cells are in part retained in the cells below. The number of bacteria to be found in the lower layers of sand or left in the water as it progresses downward through the sand becomes gradually smaller and smaller, until at the bottom the sand and the water are practically free from bacteria.

On examining bacteriologically the different sections of a normal sand bed in use for some time—say six months or more—you may find millions of bacteria in a gramme of sand taken at the surface; an inch below a few thousand, and several inches below hundreds only; at the bottom hardly any; and those few may be of a kind which is not in the applied water.

Water bacteria retained in granular bed filters do not, in the opinion of the writer, multiply. They accumulate and ultimately die. Some go through the term of their natural life and cease to live; others are, as it were, smothered by the mass of inorganic matter in which they are entangled, and others again practically starve.

The notion that the accumulation of mud in filters is to be deprecated, that the bacteria grow and multiply in the mud, and that the filtering materials should be changed or kept clean all the time, is a mistake. This is proved by the behavior of the slow sand filters, which always improve with age, a fact that has strongly impressed the writer

as the result of over ten thousand analyses made during the last nine years, not only with sand filters but with scrubbers also, at his testing station on Arch street, at Lower Roxborough, at South Bethlehem, Lancaster, and elsewhere.

Take as illustration a test made by Dr. W. J. Dugan in the writer's laboratory.

A small piece of sponge was carefully taken with sterilized forceps out of a preliminary filter or scrubber which had been in use three months. It was washed in sterilized water. The wash water was tested for bacteria. The piece of sponge when dry weighed 1 gramme. By estimating the number of bacteria which were in the water before and after passing through one gramme of sponge, we had:

Bacteria in the applied water		40,000,000
Bacteria in the scrubbed water	8,000,000	
Bacteria in the sponge	37,000	
Bacteria which had died in the sponge	31,000,000	40,000,000

In not a single case in all our experiments did we ever find the water coming out of the scrubbers worse than the applied water, although scrubbing materials were in some cases saturated with mud. On the contrary, it has always been found bacteriologically better by 50, 60, 70, 80, and sometimes 90 per cent.

It is well known that typhoid bacilli die in water in less than fifteen days, whether the water contains other bacteria or not. Thus, for instance, Prof. Ray Lankester of Oxford (England) made "a strong preparation of typhoid bacilli and introduced it in distilled water." During five consecutive days a liter of this polluted water was each day put in a Maignen filter, with the following results:

The Water Contained Typhoid Colonies.	*Before Filtration.*	*After Filtration.*
First day	300,000	0
Second day	11,000	0
Third day	3,000	0
Fourth day	1,000	0
Fifth day	66	0

The number of colonies in the water before filtration, as thus shown, became less and less every day, though nothing was done to the water. The bacilli simply died. None of the bacteria are eternal, nor is their growth without limit. The spores, or bacteria, if kept dry, may retain their latent principle of life indefinitely, like a grain of wheat in a granary, but as soon as these spores or dry germs are introduced into

water or placed in a moist environment, they sprout or come to active life, and after a time, as the rest of animated creation, they die. Sometimes their destruction is due to a kind of auto-intoxication. Thus, for instance, take a gelatin plate which has been planted with water containing bacteria; you will find some colonies very small, some large, and others larger still. It may be asked why does not a single colony cover the whole plate? Why does the growth of the colony stop at any given diameter. In the absence of any other explanation we are left to imagine that the soluble products of bacterial metabolism have poisoned the environment and prevented further growth, as carbonic acid would asphyxiate us if the air that we breathe were not renewed.

When the colonies have reached a certain point of multiplication they do not grow any more unless they are transplanted into fresh cultures. There are some bacteria which liquefy the gelatin and produce gas; these may in time spread over the whole plate, but those which are non-liquefying appear to have a well-defined self-inhibiting limit.

Some writers have affirmed that the so-called process of "ripening" filters consists in the growth, in the voids between the grains of sand and on their surface, of "beneficent" bacteria which are supposed to destroy the "maleficent" ones. This is pure romance. There is on the sand an accumulation of bacteria from the ever-increasing quantity of water passed through the filter. These are neither eating nor being eatèn, they simply die, that is all!

Charcoal.

Charcoal has been praised by some and condemned by others. Those who have condemned it have not gone far enough in their investigation. It has been asserted that charcoal is favorable to the growth of micro-organisms. This statement, which has gained credence in Europe, is based upon an error which the writer will now attempt to explain.

The first attack made on charcoal as a filtering medium appeared in a book entitled "Micro-organisms in Water." Under the heading, "Efficiency of Different Filtering Materials" (Percy Frankland, 1885), we find the following table on page 26.

On examining this table, one would naturally suppose that an accident had occurred to the charcoal filter in the last test. In any case such a single result cannot justify any conclusion and much less the condemnation of charcoal as a filtering material!

Filtering Material.	Efficiency.	Micro-organisms per c.c.		Reduction, per Cent.	Approximate Rate of Filtration per Square Foot per Hour.
		Unfiltered Water.	Filtered Water.		
Iron sponge.	Initial test	80	0	100.0	..
	After 12 days' action..........	2800	0	100.0	0.40 gals.
	After 1 month's action.........	1280	2	99.8	0.45 gals.
Animal charcoal..	Initial test.......	Too numerous to count.	0	100.0	..
	After 12 days' action.........	2800	0	100.0	0.46 gals.
	After 1 month's action.........	1280	1000	447.0 Increase	0.86 gals.

Four questions present themselves here:

1. How is it that the water applied to the iron in the initial test was different from that applied to the charcoal? In the first case there were only eighty bacteria in the applied water; in the second, the bacteria were "too numerous to count." The applied water ought to have been the same in both initial tests.

2. Why was the speed of filtration in the animal charcoal filter in the third test allowed to be nearly twice as great as in the other tests?

3. Were the filters kept working every day, all day and all night, during 30 days, or were they working only on the 1st, the 12th, and on the last day of the month, and for how many hours at a time?

4. Was the charcoal left undisturbed during all the test period?

Is charcoal favorable to the growth of micro-organisms?

In order to find out what truth or error there was in the assertion that animal charcoal was favorable to the growth of micro-organisms, the writer undertook a series of experiments which lasted a full year.

The premises were:

1. Take the animal charcoal as it is used in filters.

2. Apply water containing as few bacteria as possible in order to avoid the error of counting, as water germs, the air germs that were in the charcoal before use.

3. Do not submit the charcoal to any kind of artificial sterilization, but test it in the laboratory as it is used in daily practice.

Bacteriological Test of Charcoal.

Made in the Writer's Laboratory by Dr. W. J. Dugan, Bacteriologist.

We took three glass laboratory percolators containing about 100 cubic inches each and placed therein about 80 cubic inches of charcoal (carbo-calcis), and passed water daily, Sundays excepted, during fourteen weeks. Neither percolator nor charcoal was sterilized in any way. The examinations of the plates were made three, four, or five days after the cultures were prepared. The cultures were made in Petrie's dishes with the ordinary gelatin medium. Note was taken of the number of liquefying bacteria before and after filtration.

The following are the results:

Dates.		Water Used.		Water Filtered through Carbo-calcis.					
				Filter No. 1.		Filter No. 2.		Filter No. 3.	
Sampling.	Examination.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.
1900									
Sept. 8...	Sept. 13	36	8	412	12	300	24	620	16
10...	15	32	8	360	10	276	18	520	16
11...	15	28	8	316	8	240	14	460	20
12...	16	18	0	3,720	30	3,360	20	3,420	24
13...	16	16	0	4,140	10	4,224	8	3,700	0
14...	19	18	6	5,600	0	9,000	0	6,120	16
15...	20	16	4	4,800	0	7,740	0	5,720	0
17...	22	22	4	4,500	0	6,480	0	5,340	0
19...	22	16	6	4,160	0	5,940	0	4,640	0
20...	23	28	10	3,920	0	4,860	0	4,180	0
21...	26	34	12	3,064	0	4,388	0	3,358	0
22...	27	16	4	2,677	0	3,346	0	2,534	0
24...	28	20	4	2,326	10	2,634	8	2,196	14
25...	29	14	0	2,032	6	2,216	0	1,968	16
26...	29	120	44	1,800	0	2,098	12	1,920	16
27...	Oct. 2	84	16	1,660	0	2,430	30	1,808	18
28...	2	36	18	1,560	0	2,180	8	1 620	2
29...	3	16	0	1,500	0	2,032	6	1,520	0
Oct. 1...	4	16	2	1,250	0	1,460	0	1,280	6
3...	6	18	0	1,060	0	1,200	0	1,040	0
4...	10	18	4	980	0	1,120	0	990	0
5...	10	1,048	46	926	12	1,076	8	910	2
6...	9	16	0	624	0	1,060	16	740	0
8 ..	11	16	0	60	0	180	0	36	0
9...	13	26	0	40	0	190	0	16	0
10...	14	28	0	16	0	80	0	14	0
11...	15	26	0	10	0	18	0	14	0
12...	16	8	0	4	0	2	0	8	0
13...	17	10	0	0	0	0	0	4	0
15...	19	8	0	0	0	0	0	4	0
16...	20	10	0	0	0	0	0	2	0
17...	20	980	90	6	0	0	0	6	0
18...	22	740	80	4	0	4	0	6	0

Dates.		Water Used.		Water Filtered through Carbo-calcis.					
				Filter No. 1.		Filter No. 2.		Filter No. 3.	
Sampling.	Examination.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.	Total number of bacteria per c.c.	Liquefying.
1900									
Oc. 19...	Oct. 25	850	60	6	0	4	0	8	0
20...	24	1,600	120	4	0	4	0	6	0
22...	25	1,360	80	6	0	6	0	4	0
23...	26	1,260	130	4	0	4	0	4	0
24...	27	2.500	120	0	0	0	0	4	0
25...	29	2,200	120	2	0	8	0	0	0
26...	31	1,650	80	6	0	8	0	2	0
27...	Nov. 1	1,250	90	4	0	6	0	4	0
29...	2	1,420	100	10	0	12	0	6	0
31...	5	1,340	100	8	0	0	0	4	0
Nov. 1...	5	1,650	140	4	0	6	0	4	0
2...	6	1,900	150	0	0	6	0	8	0
3...	8	2,150	180	4	0	0	0	4	0
5...	8	1,720	130	0	0	6	0	2	0
6...	9	3,420	220	4	0	0	0	2	0
7...	10	3,840	190	6	0	2	0	2	0
8...	12	2,000	160	1	0	8	0	2	0
9...	13	2,900	260	7	0	6	0	11	0
10...	14	4,350	200	4	0	0	0	3	0
12...	16	2,700	160	8	0	7	0	0	0
13...	17	1,920	140	3	0	0	0	5	0
14...	17	1,600	100	0	0	2	0	0	0
15...	19	2,090	160	8	0	6	0	4	0
16...	20	2,630	200	8	0	0	0	4	0
17...	21	5,110	270	6	0	8	0	12	0
19...	23	2,700	210	4	0	10	0	7	0
20...	24	3,200	130	12	0	6	0	12	0
21...	24	5,250	400	2	0	10	0	6	0
22...	26	2,640	230	6	0	4	0	2	0
23...	27	18,600	800	10	0	15	0	12	0
24...	28	6,400	500	8	0	6	0	11	0
26...	30	5,000	230	7	0	11	0	5	0
27...	Dec. 1	5,820	320	4	0	5	0	2	0
28...	3	8,150	400	3	0	9	0	1	0
30...	4	13,000	590	6	0	5	0	2	0
Dec. 1...	5	11,560	500	9	0	7	0	4	0
3...	7	11,000	410	4	0	6	0	7	0
4...	8	5,640	160	3	0	2	0	6	0
5...	9	6,950	200	3	0	4	0	1	0
7...	11	9,760	190	6	0	7	0	4	0
8...	12	12,100	210	2	0	8	0	1	0
10...	14	10,620	170	3	0	4	0	8	0
11...	15	9,340	140	6	0	2	0	3	0
12...	17	13,200	220	7	0	0	0	2	0
13...	18	16,240	340	1	0	5	0	3	0
14...	18	10,430	260	0	0	8	0	11	0
15...	19	9,210	160	6	0	8	0	2	0

During the first period—from September 8th to October 16th—with three exceptions the water applied to the filters was practically pure. The number of bacteria found in the filtered water was altogether out of proportion to that introduced into the filter with the applied water. An interested or insufficiently informed witness would have

rushed into print at once without waiting for the end and would have said that the charcoal was a breeder of microbes, a nest of infection, a dangerous thing, etc., while on the contrary it was simply purging itself of its own harmless air germs. Any one familiar with the work of Professor Tyndal, entitled "Floating Matter in the Air," will remember his explanation of the fact that the desiccated air germs or spores require a certain period of incubation in water in order to become adult bacteria. This is just what takes place in granular bed filters at the beginning of their use. Charcoal, for instance, contains fourteen times its volume of air and therefore a corresponding quantity of dry air germs. These, under the influence of the moist environment, become soft like wheat in a field after the rain; they germinate or grow until they are able to move and work their way out.

On October 11th the filters were rid of all their pre-existing or "constitutional" bacteria, and the filtered water was as good as the applied water. This continued till October 16th, when a change was made.

Instead of feeding the filters by hand with pure water once during the day, allowing them to rest at night, an arrangement was made to filter raw water in a continuous manner, day and night, with the result that during the three following months the filtrate maintained itself practically free from bacteria all the time.

Surely this is sufficient to show that animal charcoal is not, *per se*, favorable to the growth of micro-organisms.

The observers who have found fault with charcoal have not carried their experiments far enough. They have assumed that charcoal could be sterilized by heat as easily as glass, which is not the case. They have also ignored the fact that a charcoal "granular bed" filter is not made to be handled in the same manner as the porcelain "porous wall" filter! It is made to filter water, not to be put in the fire. A process of sterilization which is suitable for a porcelain filter is not necessarily good for a charcoal or sand filter.

The "porous wall" filters are sterile when they are new; they come from the fire and contain few, if any, air germs; that is why they give sterile water at first.

The "granular bed" filters, on the contrary, are not free from air germs when new; they contain spores and dry germs which at first appear to make the water worse; but after a short period of service, these spores or germs have disappeared and the filters become good, and remain good as long as they are not disturbed.

This was confirmed by experiments with sand filters. We took three

percolators and filled them with sand; the sand in the No. 1 and No. 2 was not washed, but was subjected to dry heat; the sand in No. 3 was washed before being placed in service. The following are the results:

TEST OF SAND FILTERS.

RESULTS FROM OCTOBER 9 TO OCTOBER 19.

Date of Operation, 1900.	*Number of Bacteria in Applied Water.*	*Number of Bacteria in Filtered Water.* *Filter No. 1.*	*Filter No. 2.*	*Filter No. 3.*
Oct. 9	28	20	10	800
10	28	16	8	120
11	24	30	100	330
12	8	108	150	140
13	10	24	20	100
15	8	18	20	82
16	10	14	12	50
17	8	12	15	56
18	8	4	6	12
19	8	6	6	12

We see that it took four days for the spores in the dry sand to develop into bacteria. Those of the sand which had been washed had evidently been incubated and developed into bacteria by the water used to wash it. The first filtrate was the worst. It took nine days to "ripen" the three filters; that is, to free them from their "constitutional" bacteria.

At this time it was noticed that the metal screen at the bottom of one of the percolators had been displaced. We took the "ripe" sand out carefully, removed the metal screens, and made a gravel underdrain similar to that used in big filters. We replaced the "ripe" sand carefully on this underdrain and proceeded with the filtration. It should be stated that the gravel had not been washed or sterilized in any way; it was taken out of the warehouse, and was evidently covered with dust and dry air germs or spores. It will be observed (page 31) that after restarting the filters we have the same curve—the same rise and fall—in the number of "constitutional" bacteria as with the charcoal. It took twenty-one days to "ripen" the gravel.

There is nothing new in the discovery that the water coming from an unsterilized granular bed filter contains many bacteria, but what is new is the fact that if you continue filtering water through granular beds long enough, without disturbing the filtering materials, these will sterilize themselves without the help of dry heat, steam, or chemicals. It is therefore an error to say of granular charcoal or sand filters that they must be cleaned or artificially sterilized frequently.

The following is the record of the performance of these filters after the change:

TEST OF SAND FILTERS (CONTINUED).

RESULTS FROM OCTOBER 10 TO NOVEMBER 15.

Date of Operation, 1900.	*Number of Bacteria in Applied Water.*	*Number of Bacteria in Filtered Water.* Filter No. 1.	Filter No. 2.	Filter No. 3.
Oct. 20	12	416	120	108
22	8	860	1120	1500
23	8	2280	6720	3460
24	10	2820	7260	3560
25	32	3360	9000	2860
27	10	1520	2840	1060
28	10	2460	6520	2240
29	8	212	1360	190
31	8	200	1400	180
Nov. 1	10	180	1280	160
2	10	90	920	84
3	10	80	656	54
5	8	68	592	58
6	10	72	216	40
7	8	100	196	46
8	6	84	412	49
9	8	46	440	12
10	8	36	70	24
11	8	60	72	32
13	8	32	42	24
14	8	16	10	8
15	8	10	8	6

DOMESTIC AND ARMY FILTERS.

We have seen that water can be deprived of dangerous bacteria and rendered safe for drinking by filtration through improved municipal slow sand filters as at South Bethlehem and Lancaster. We have also seen that failure has sometimes attended the operation of some of the large slow sand filters in this country—as for instance at Poughkeepsie, Hudson, Little Falls, N. Y., Ashland, Wis., Rock Island, Ill., etc. Unsatisfactory sanitary results have also been registered at certain times with the mechanical filter plants, Newcastle, Pa., Lexington, Ky., etc. At Bangor, North Wales (Great Britain), an epidemic of typhoid fever raged for some time and ceased when the use of the municipal filters was discontinued.

The question of domestic filters, therefore, must be of real interest to every one of us, not only for those who reside in cities, but also for those who live outside city lines. In country residences and on farms the water supply is generally drawn from shallow wells, surface springs, or cisterns. These supplies are very liable to be bad.

Armies, likewise, are peculiarly exposed to water-borne diseases, par-

ticularly to dysentery. Any government which neglects to provide ample means for purifying the water supply of armies in the field is little short of criminal.

The English and French armies in the Crimean War lost 25 per cent. of their effective force through diseases due to bad water. The English expedition, organized for the relief of Gordon, in 1884, on the contrary, broke all records in health. Twenty-two thousand men returned home from Egypt after a march up the Nile and through the desert without having lost a single man from bad water. These troops were supplied with filters designed by the writer.

The relation between bad water and disease is so well established that it would be simply foolish to ignore it.

A simple narration of the successive steps in the writer's search for methods of purifying water for domestic and army use may be of interest.

In 1878 the need of a system of water purification was brought home to the writer while residing in London, England, and it was then that he determined to consecrate the rest of his life to this particular study.

It was not until 1882 that he had some sort of a water filter to show. In 1884 it was perfected. The invention has since been developed to its present state of perfection.

The first requirement suggested by the English sanitary engineers was for a filter that could be cleaned; the second, for one that would contain no substance capable of decaying; the third, for a filter that would not only clarify the water well but would also remove the organic matter and metallic poisons in solution.

Then came a demand for the removal of lime from the water.

About the same time (1883) the English War Department became interested in water filtration and called for designs of:

1. Pocket filters.
2. Filters for officers' "mess."
3. Filters for a "squad."
4. Filters for a "section" of soldiers.
5. Filters for a "company."
6. Filters for a "whole regiment."
7. Special filters for carrying on pack-saddles, on water-carts, on the ambulance and company carts. The forms were to be varied to suit the particular kind of transportation desired; some were to be made for carrying by hand and others on men's backs, others again to be moved on wheels.

The public also demanded various forms of filters:

8. Crockery filters, like coolers, for use in the kitchen.

9. Decorated porcelain filters for the dining-room.

10. Stationary filters for attachment to the wall and connection with the service pipe in the kitchen or pantry.

11. Other filters were wanted to filter the water in the garret along-

Fig. 11.—The Different Kinds of Water Filters Designed for Army and Home Use by the Author in 1884.

side the house tank, the filtration going on slowly day and night and the filtered water accumulating in the tank, from which it was drawn, as required, for baths, kitchen, and general use.

12. The writer found in this country another want, essentially American, *i. e.*, a filter that should filter the water as fast as required for all usages without storage! A filter that would do in one hour what takes twenty-four hours abroad.

The very first filter made by the writer (in 1878) was designed to clarify wine, brandy, and whiskey. It consisted of a tinned copper filter case and a hollow wooden filter frame covered with canvas cloth of the kind used in filter presses. A few sheets of filter paper were beaten in hot water, the water was squeezed out, and the pulp beaten again in some of the first fluid (brandy or whiskey) which was to be filtered. This first fluid or emulsion would carry the floating pulp onto the surface of the cloth, where it would become deposited evenly and make a new filtering membrane having the appearance and consistency of a thick sheet of blotting paper. The first fluid was, of course, refiltered. It was passed over and over again, several times through the filter, until it came out perfectly bright. Many of these filters are still in use in old and New England.

The first Maignen water filter was made in 1879. Woolen felt was substituted for canvas, and finely powdered charcoal took the place of the paper pulp. The reason for this addition of a filtering membrane was the conclusion that no textile, however carefully made, could have pores absolutely uniform in size. There appeared only one way to insure a homogeneous surface, and that was to float in the first liquid very fine particles of suspended matter which would at first flow in greatest quantity toward the largest passage and in less quantity toward the smallest pores, until after a time the whole surface would offer the same resistance.

Felt was selected for water filtration because it was known to have been used from time immemorial in the arts for filtering purposes. The felt bag was the filter of the alchemists and it was sometimes called "Hypocrates' sleeve." It is felt which has given the name "filter" to the device intended to separate solids from liquids.

This first water filter with felt and charcoal gave good results for about a week. Then the filtered water began to have a faint odor; at the end of another week it smelt like bad eggs, and in three weeks the microbes had made short work of the wool—it was rotten. There never was a second felt filter made for water.

In 1880 the writer found that the art of spinning the mineral fiber known as asbestos had been recovered after having been lost for many centuries (the ancients had used asbestos cloth for cremation, very much as we do now), but it was necessary to mix cotton with the asbestos fiber as a binder. The cotton soon decomposed in water and gave a bad taste to the water. Later it was found possible to dispense with the cotton, but on the condition of using oil. This was nearly as bad and

gave a very objectionable taste to the filtered water. So, in order to get rid of these objectionable features, the asbestos cloth was baked in a furnace at such dry heat as would burn a straw. It was more than ten years before mechanics devised machinery capable of spinning and weaving pure asbestos fiber.

Many other difficulties were of course encountered. The greatest was that of spinning the asbestos thread loose enough to have filtering qualities and yet strong enough to stand the strain of weaving. This was ultimately overcome.

It was not enough to have a good filtering cloth. It had to be used to advantage. In the first filters made, the cloth was sewed in the shape of a cone and tied over a perforated hollow cone for the small domestic filters, and over tinned copper hollow filter frames for the larger filters. Then the powdered charcoal was deposited on the cloth, as already explained, by being mixed with the first water put into the filter. If the tying of the cloth on the cone, or the sewing was defective, the charcoal would come through with the filtered water and thus indicate the defect. It was not long before it was found that the tinned copper frames underwent "electrolysis." The metals were half dissolved by the pure water in less than one year.

At that time two suggestions presented themselves—(1) to do away with the metal as a support for the asbestos cloth, and (2) to multiply the filtering surface, so as to get more water. The evolution from the cone to the concertina shape of the present filter frames then followed. Let us fancy that we have before us a cone; let us squash it like an opera hat; we shall then have a large surface of cloth in a comparatively small space. Or let us take a plain sack or cloth cylinder such as is used to hold wheat; let us tie one end, then insert inside the sack a ring of the full diameter of the sack to distend it. Then let us pass a small ring outside the sack to constrict it; then another large ring inside, and another small ring outside, and so on, six or eight times, and we have then the notion of the concertina shape. We have more than 24 sq. ft. of area in a space one foot square, eight inches high.

But we then met with trouble; the inside rings did not prevent the two folds of the cloth from coming together and adhering to one another under the force of suction inside or compression of the water outside.

These changes, which are described in a few words, did not succeed one another in so short a time. Weeks, months, and years intervened between the different steps, and the new ideas came when they were

least looked for. It was the sight of a wire-netting screen in a custom-house office in Milan, Italy, that gave the idea for the next step. It was made of spiral wire. A number of discs were made and used in a lecture at Rome within a few days of the first thought. They worked admirably; the space between the two edges of the spirals prevented the two cloths touching one another and made a good draining system. The first discs were nickeled and some silver-plated, but it was still metal and we knew that it would not stand long.

The writer was then back in London. He took his spiral wire frame to a pattern-maker, explained to him that he wanted a corrugated and perforated disc in pottery to have the same properties as the wire disc, and in less time than it took to explain what was wanted the pattern-maker had settled the problem.

He took a piece of wood about one inch thick and six inches square and cut parallel triangular grooves in each face deeper than half the thickness of the block, those in one face at right angles to the ones in the other face, so that at each intersection of a groove with those on the opposite side a hole was made, giving a corrugated and perforated block that would secure in a filter practically the same effect as the spiral wire cloth.

This pattern was taken to the pottery and served as a model for moulds with which the porcelain discs now used are made.

To have found a filtering cloth not subject to decomposition in water, and to have arranged it so as to provide the maximum area of filtering surface within a given space, was not enough to constitute a water filter answering all the requirements, although asbestos cloth alone, when well felted, is able to clarify water to perfection—better than "granular beds" and "porous walls." It has been found capable of sterilizing wine without changing the taste, color, or any dissolved property. It can, therefore, *clarify* water, but it cannot *purify* it.

It was then decided to deposit on the surface of the asbestos cloth some finely powdered charcoal, the particles of which were to be of such size as not to rise to the surface of the water nor sink to the bottom. It must permeate the whole body of the water and remain in suspension for some time. The filtration is then started, and as the water passes through the asbestos cloth the current draws the small particles of charcoal toward the surface of the cloth.

If there be in the asbestos cloth some pores or channels larger than others, the water flows in the direction of the largest openings with the greatest velocity. It therefore carries in that direction the greatest

number of fine particles of charcoal and this goes on automatically all over the asbestos cloth. It is easy to understand that in this manner the filtering surface is equalized and rendered perfectly homogeneous.

It should be stated that the filtration through asbestos cloth does not take place as through a sieve or as through a "granular bed" or a "porous wall." The water ascends or descends along the asbestos filaments as oil along a lamp wick. This is evidenced by the fact that

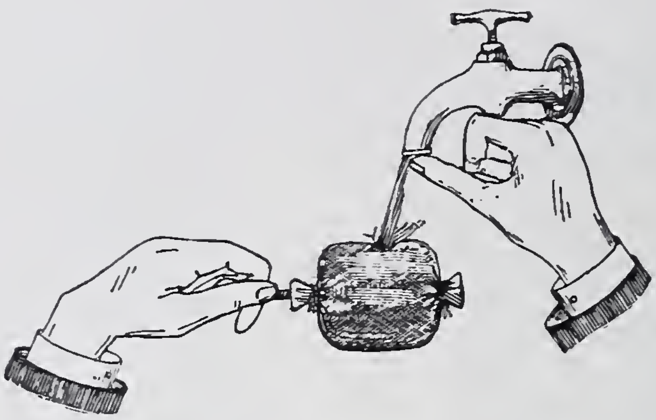
FIG. 12.—APPEARANCE OF THE INNER ASBESTOS CLOTH OR CORE *A* IN WATER, BEFORE IT IS COATED WITH THE FINELY POWDERED "CARBO-CALCIS." THE FILTRATION TAKES PLACE BY CAPILLARITY, AND NOT BY STRAINING AS IN OTHER FILTERS.

FIG. 13.—APPEARANCE OF A MAIGNEN FILTERING ORGAN IN WATER. OBSERVE THE HAIRY APPEARANCE OF THE ASBESTOS FELTED CLOTH. THESE LOOSE FIBERS FILL THE MESHES OF THE CLOTH AND PREVENT THE MUD PENETRATING.

when a filtering organ, such as has been described, is placed in a vessel containing water and is used as a syphon, every drop of water which is in the vessel is sucked up and filtered out.

With any other material the syphon would be broken off as soon as any part of the organ would be above water. The air would penetrate through the pores of porcelain or any other kind of porous or granular filter. The air does not go through wet asbestos cloth.

The invention was at this stage—asbestos cloth stretched on frames and covered with powdered charcoal—when the British army was equipped with filters designed by the writer for the Egyptian campaign. The instructions were to wash off and renew the fine charcoal once a week. The filters could thus give a very large quantity of water of high quality, as has been proved by the results already alluded to.



Washing the Mud off the Surface of the Filtering Organ.

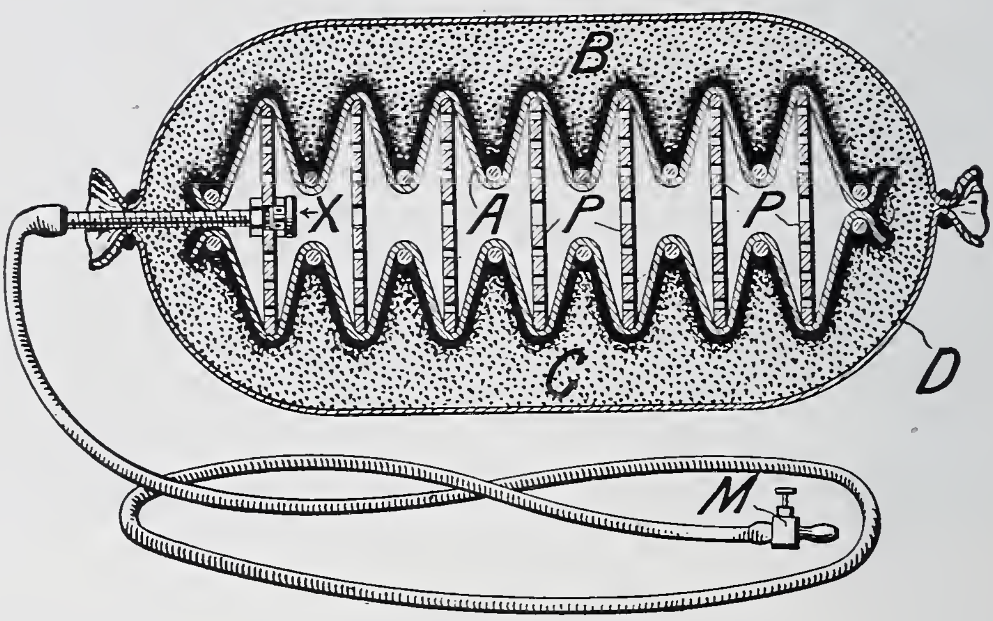


Fig. 14.

A is a special asbestos cloth arranged in concertina shape by means of porcelain discs *P P* which distend the sack and asbestos cords which constrict it. *B* is a thin layer of finely powdered "Carbo-Calcis." *C* is a thick layer of granular "Carbo-Calcis." *D* is an outer asbestos cloth or sack.

The next step in the progress of the invention was that which consisted in surrounding the powdered charcoal with a thick layer of granular charcoal. This had the result of lengthening the life of the powdered charcoal, as most of the mud was retained by the coarsest layer, and, instead of having to be cleansed once a week, the filters in which the granular charcoal was placed could go a month or more without washing.

Another step, and this was the last, consisted in covering the granular charcoal with another asbestos cloth. This would keep away the mud from both the granular and the powdered charcoal, so that these porous materials can keep their porosity and power of oxidation for an indefinite length of time.

Thus constructed, the filter was found capable of removing from water not only the bacteria and the suspended matter, but also the dis-

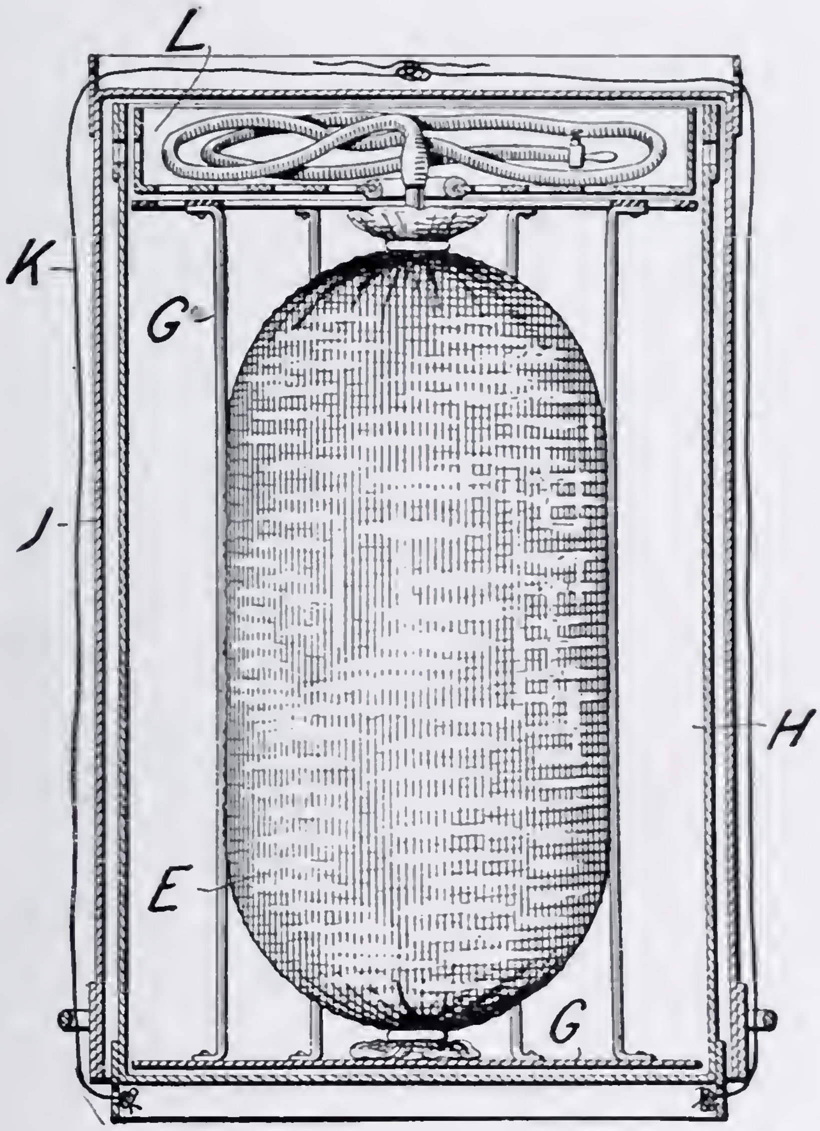


FIG. 15.—U. S. ARMY "SECTION" FILTER (MAIGNEN SYSTEM).
Packed for transport in two telescoping buckets with cradle to protect the filtering organ against injury during transportation or use.

solved organic matter, such as urine, and the dissolved metallic poisons, such as lead, copper, and iron.

This power was not due to the asbestos, nor to the granular charcoal, nor to the powdered charcoal alone, but to the combination of the whole.

In the schools of hygiene in Europe this filter is used to illustrate the power of filtration. Thus Dr. Arnould, of Lille, France, in his

book, "Nouveaux Elements d'Hygiene," says: "An elegant experiment consists in adding to a glass of water a few drops of urine. You show the students that this polluted water discolors instantly a weak solution of permanganate of potash put, drop by drop, in the water; you then filter the water through a Maignen filter, and doing the same as before with permanganate, you show that the pink color of the reagent is not in any way altered."

Professor John Marshall, of the University of Pennsylvania, and Dr.

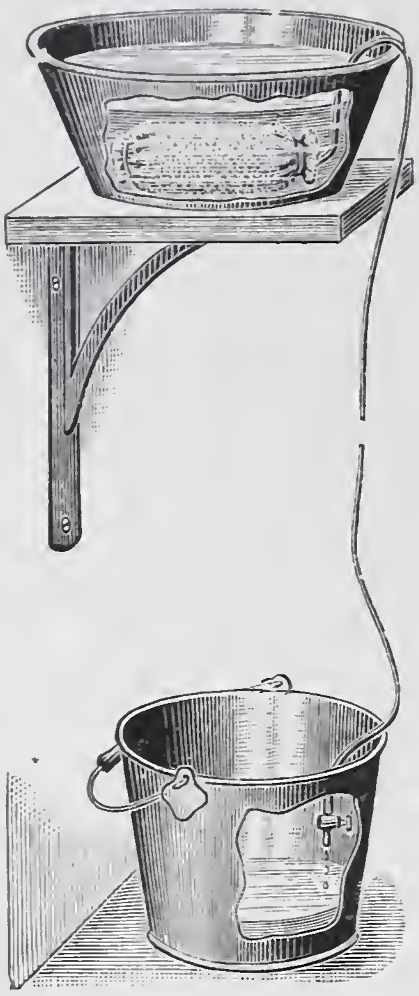


Fig. 16.—Filtering from Dish to Bucket.

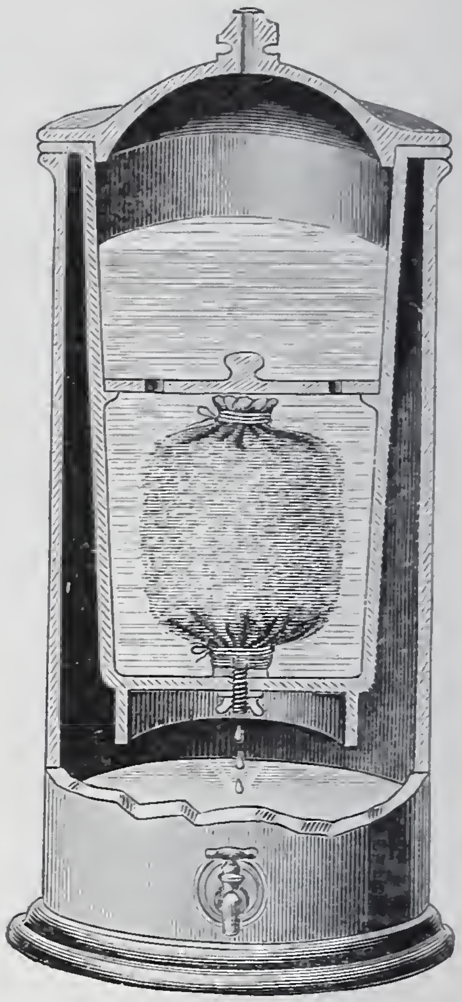


Fig. 17.—"Cottage" Filter. Form Best Known in England and Europe for Family Use.

C. H. White, of the U. S. Naval Museum of Hygiene, Washington, D. C., have found it capable of removing dissolved arsenic.

Some have called this the power of "oxidation," others "molecular attraction," others "contact" (as in the case of spongy platinum); others again, the "power of the powders."

Whatever the explanation the fact remains that this filter removes dissolved organic matter and dissolved metals. It does not remove sodium chlorid, nor sugar, nor the salts of the metals of the first series: lithium, sodium, potassium; it removes a small quantity of the salts

of the metals of the second series: calcium and magnesium: and the entirety of the salts of the heavy metals: lead, iron, copper, mercury, etc.—dissolved in water.

Porcelain filters are used for separating bacteria from their toxins. The filtered fluid is as toxic after filtration as before filtration. If such a fluid be passed through the Maignen filter it is deprived of both

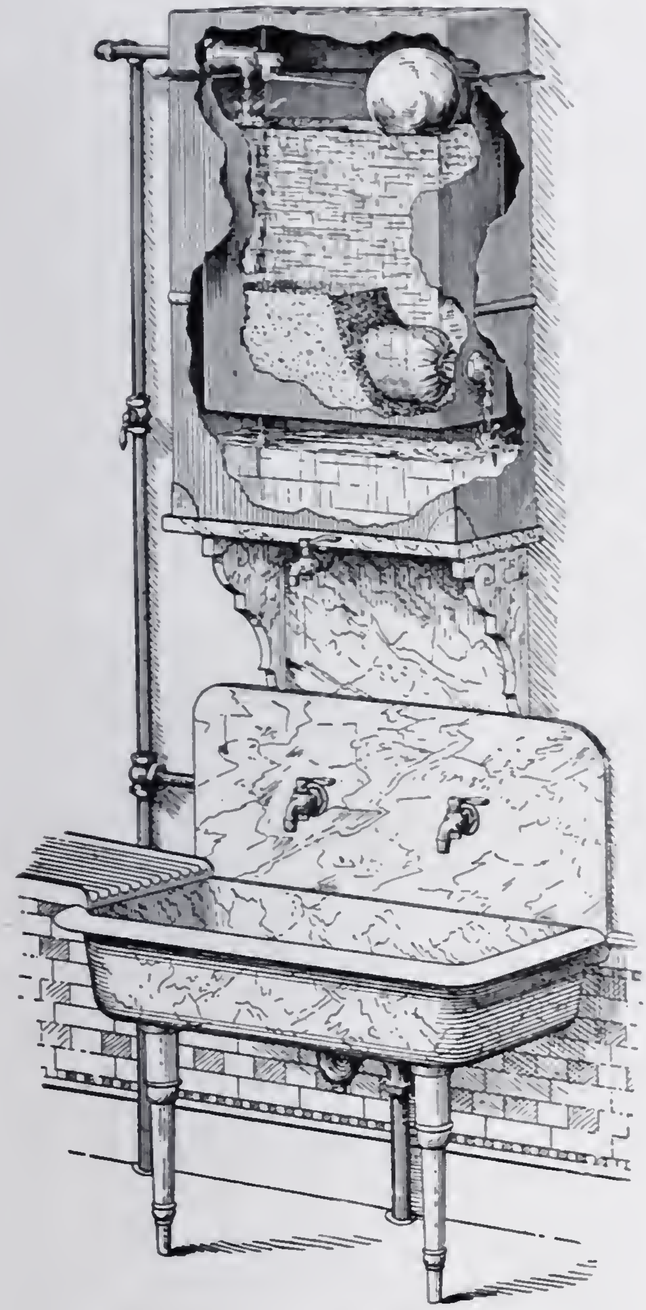


Fig. 18.—"Service" Filter.

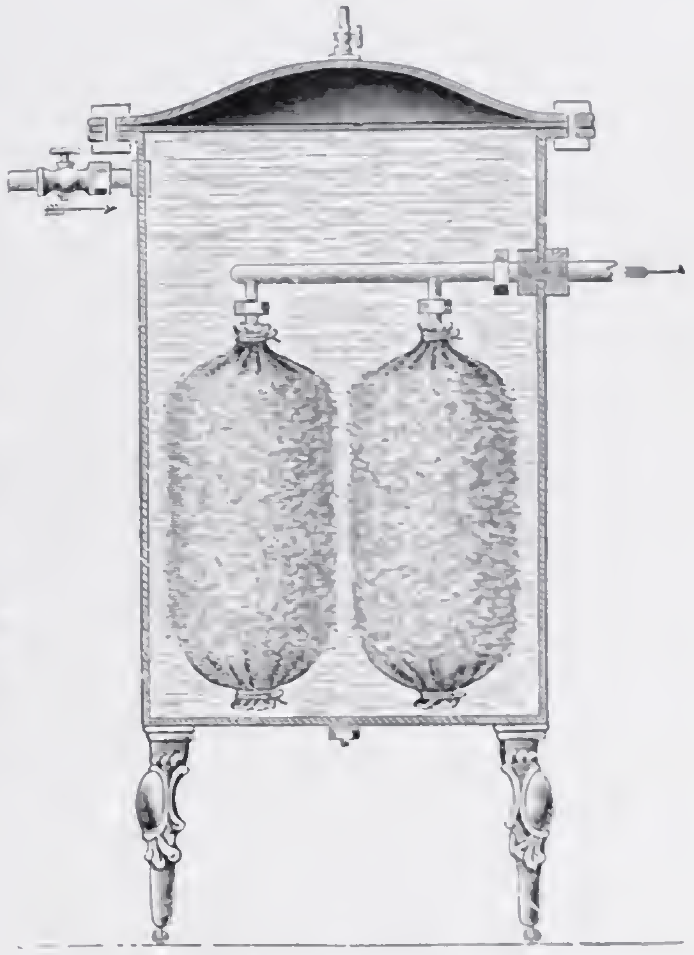


Fig. 19.—Asbestos and Charcoal Pressure Filter as Used in the Schools of Philadelphia.

the bacteria and the soluble toxins. The following are a few of the experiments which have been made in order to ascertain this fact:

By Dr. Macé, Nancy:

"A virulent anthrax broth was prepared; five drops sufficed to kill a guinea-pig. This broth is put directly into the filter; water is afterward put in the filter. The water which has traversed the polluted

filter is collected and is injected at the dose of two c.c. to two guinea-pigs. These are not affected in any way. This operation is repeated several times during one month with the same filter without sterilization or cleaning, and with the same result. The guinea-pigs inoculated with the polluted water before filtration died. Those inoculated with the filtered water did not suffer."

By Dr. Burlureaux, Paris:

"Water charged with anthrax germs kill inoculated mice. The same water after filtration has no effect on them."

By Dr. M. Gillespie, in the Maignen Laboratory, Philadelphia:

"A bouillon culture of diphtheritic bacteria was prepared by inoculating ordinary sterilized bouillon with a pure culture of diphtheria bacillus. It was placed in the incubator for development and kept at 37.5° C. for one week. At the end of that time, it was of such virulence that half a cubic centimeter per hundred grammes of weight of guinea-pig would be sufficient to kill the animal. This bouillon culture was filtered through eight layers of filter paper to free it of the bacteria. To the resulting pure toxin one-half of 1 per cent. of tricresol was added as a preservative. One and seven-tenth cubic centimeters of this toxin was inoculated into a guinea-pig of 270 grammes weight. The animal died in forty-eight hours.

"About 300 c.c. of this toxin were then filtered through a Maignen filter; the filtrate was as clear as water; the yellow color of the bouillon had been removed. One-half of 1 per cent. of tricresol was added, as had been done in the case of the unfiltered toxin. A guinea-pig of 274 grammes was inoculated with 1.7 c.c. of the filtrate, and it showed no symptoms of suffering, and is now enjoying perfect health."

The filter also removes gases and bad taste. This quality is noticeable with the Philadelphia water which at certain times of the year has a very unpleasant taste and odor due to sewage and organic pollution. The odor is particularly strong when the water is heated or boiled. After filtration by this process the water is free from bad odor or bad taste.

Figs. 16, 17, 18, and 19 show different ways of using the Maignen asbestos and charcoal filtering organs.

The following is the record of some of the school filters (Maignen system) after five years' constant use, during which time it was not cleaned more than four times.

	Bacteria per c.c.
Raw water applied to the filter of the "U. S. Grant" School, Seventeenth and Pine, Philadelphia,	2800
Filtered water	16
Efficiency, 99.38 per cent.	
Raw water applied to the filter of the "Hollingsworth" School, Locust above Broad, Philadelphia,	2900
Filtered water	22
Efficiency, 99.21 per cent.	

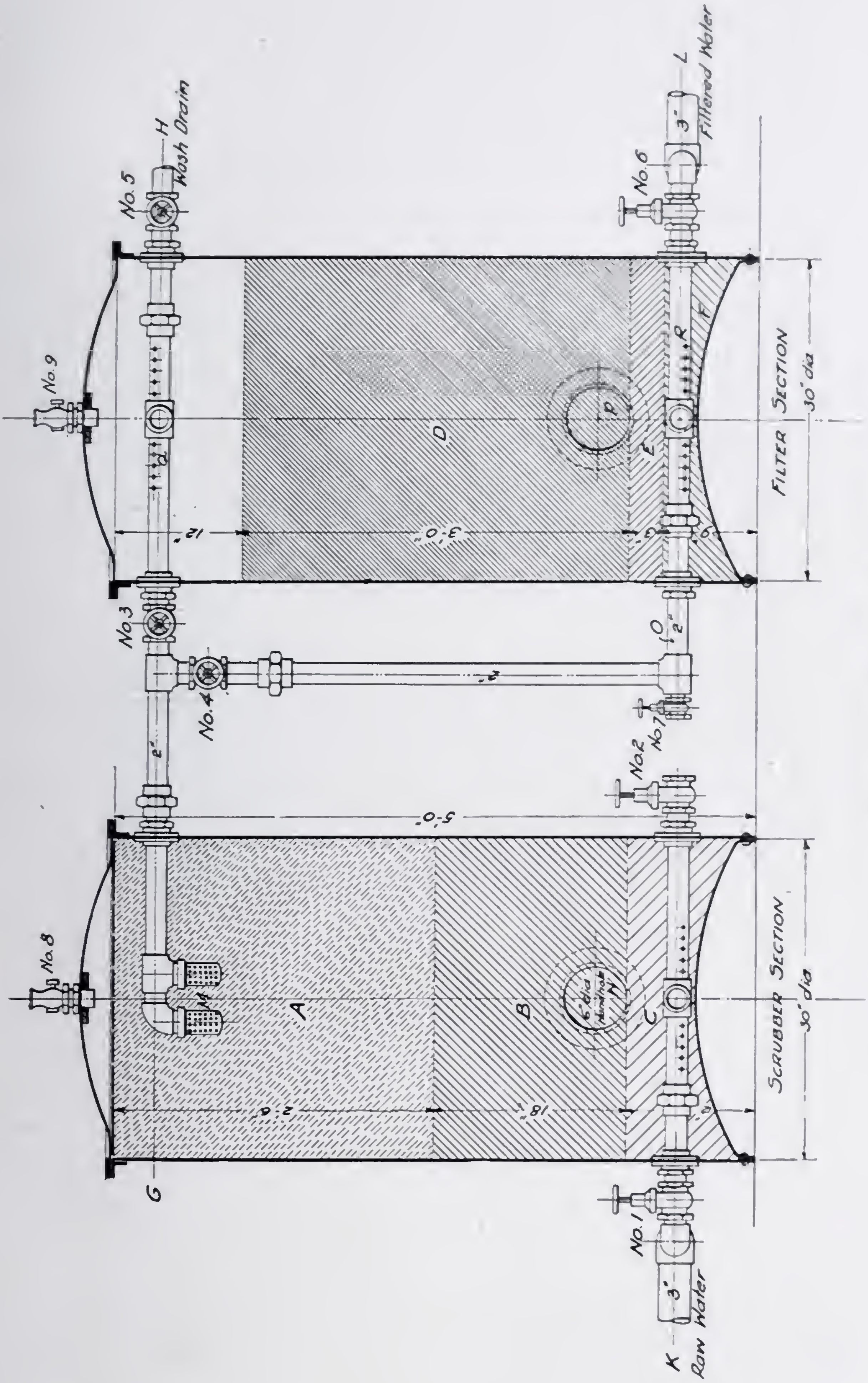


FIG. 20.—DOUBLE PRESSURE FILTER (MAIGNEN SYSTEM).

Little need be said about that class of filters which are installed in cellars and are supposed to filter the water as fast as if there were no filter at all. The writer has made some of this kind with coke and sponge in a cylinder as a scrubber, and granular charcoal in another cylinder, as a final filter. They should be kept going without cleaning or disturbance as long as they give enough water, and when they cease to do so all the materials should be taken out, thoroughly washed, and replaced carefully in the cylinders. Partial cleaning is not advisable and daily washing by reverse current much less so, because, as we have already seen, granular bed filters are never as good after being disturbed as when left alone. "Make room for the mud" and "disturb the filter as little as possible" are the thoughts which have been foremost in the mind of the writer for some time past.

Most engineers and inventors of filters have hitherto made the mistake of asking too much from a single operation or process. The writer was at one time under the same narrow influence, but he was years ago brought to his senses while attempting to filter large quantities of wine with asbestos cloth in the south of France and in Algeria. He had a very fine asbestos filtering cloth and expected great results from it. If the wine came out bright the quantity filtered was insignificant, and if the flow was forced by pressure or suction in an attempt to get a larger quantity the filtered wine was not clear. In this dilemma he decided to filter twice in succession, first through an open asbestos cloth, which would remove 60 or 80 per cent. of the organized cells (which made the wine cloudy), and next through a closely woven asbestos cloth, which would finish the clarification. The result was a revelation. The two operations gave, in the end, both quality and quantity.

From that time onward preliminary filtration was established in the mind of the writer, and it is safe to predict that in the future a multiplication of filtering operations will prevail over single operations. Subdivide and distribute the labor according to the capacity of each laborer. Do not put the work of a porter on the shoulders of a gentleman, and do not put the work of a gentleman in the hands of a porter.

In dealing with the purification of large water supplies it is well to consider the different subdivisions of the work as now understood:

1. The *idea of sedimentation* in reservoirs is to retain the particles of coarse silt and sand which are heavy enough to fall by their own weight to the bottom; also as a reserve to draw from in case of acci-

dent or during freshets, and also in order to render the transition from the good to the bad water less marked owing to the admixture of the two waters in the reservoir.

2. The *idea of scrubbing* is to retain the greater part of the bulky and light suspended matter, such as algæ, leaves, clay, etc., which clog the filter prematurely. Scrubbers designed for this purpose should lose the least possible amount of head.

3. The *idea of prefiltration* is to help the final filters by doing some

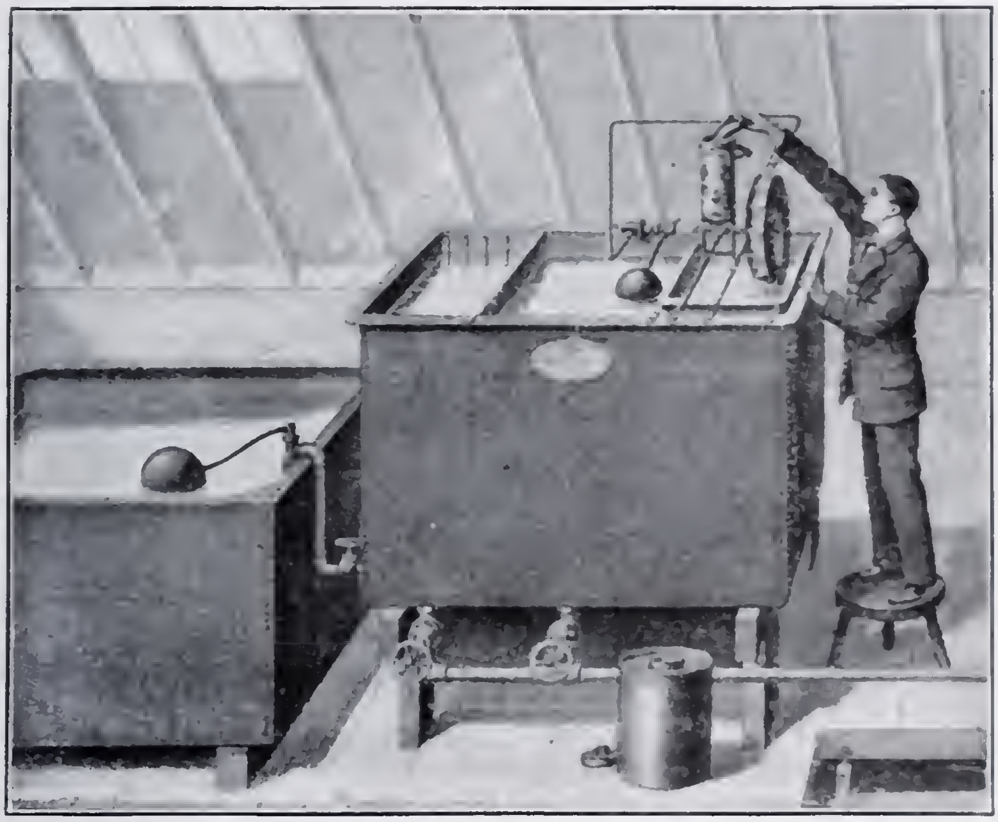


Fig. 21.—Home Water-softening Apparatus (Maignen System).

of their work and thereby lengthening the "runs" and diminishing the risk of bad work.

4. The *idea of filtration proper* or *final filtration* is to retain the bacteria left in the water after the preliminary treatments.

Many other subjects relative to water purification, such as coagulation, influence of the air on filters, positive and negative head, loss of head, rates of filtration, etc., might be discussed, but would extend the limits of this paper unduly. The question of the removal of lime from water has, however, already been raised in this paper.

Lime cannot be removed by filtration. The writer invented in 1884 a water-softening process, which has continued in vogue in England to this day, for country residences and public institutions in districts where the water is hard.

In this process the reagents—mostly lime and soda—are prepared in a powdered state, in the proportions indicated by the analysis of the hard water. The softening powder is kept dry in iron barrels or tins.

An automatic apparatus with softening tank is installed at the top of the house. As the water comes into the tank it passes over an overshot water-wheel which provides the power necessary to drive the powder out of the hopper through a regulated door. The hopper is filled once a week or so by the gardener or house-servant. The powder and the water come together in the desired proportions into the tank. It is filtered after the chemical reactions are ended and no trouble has ever been experienced, though more than four hundred installations have been in use in England during the last fifteen or twenty years.

These installations deal with the whole water supply of houses,

Fig. 22.—Water Pipes Incrusted with Lime Deposit from Hard Water.

not only to prevent incrustations in hot water pipes but also to supply soft water for drinking, cooking, baths, etc.

The powdered preparation alluded to is known as "anti-calcaire," and can be obtained and used without apparatus. It can be added to water in any kind of tank, tub, or vessel. The powder is mixed with the water in the evening, and the next morning the water is soft and clear and the lime is at the bottom of the vessel as a heavy sediment.

Dr. Burlureaux, of Paris, and the writer established fifteen years ago that the chemical purification of water, which is effected by this softening process, brings about as a natural consequence its sterilization.

The tests of Dr. Burlureaux, which lasted more than two years, and in which quite a number of the most noted Paris bacteriologists par-

ticipated, were made with various kinds of bacteria: cholera, typhoid, coli, streptococci, and anthrax.

The following is the record of one of these experiments, made with anthrax bacillus, and which may be taken as a type of the technique followed:

"To one-half liter of hard well water was added a culture of anthrax. Ten drops were planted on a gelatin dish as control. One-half gramme of 'anti-calcaire' was added to the sample of polluted water making the dose 1 : 1000. Samples of ten drops were taken at different hours and planted on gelatin, with the following results:

Date of Reading of the Cultures.	Samples Planted, Dec. 22.			
	At 7 A. M. Control.	At 10 A. M. Treated Water.	At 3 P. M. Treated Water.	At 6 P. M. Treated Water.
Dec. 24, at 3 P. M.	The plate was covered with colonies of B. anthrax and B. fluorescens viridis.	About half the number of colonies as compared with the control plate.	No colonies apparent.	Nothing.

DISCUSSION.

Henry Leffmann.—The problem of water supply is an acute one, and in view of the constantly accelerating rush into cities, the problem will become more and more serious. In most parts of the world, ordinary wells or springs will not suffice for cities, and they must draw their water from rivers and other large sources, which are sure to be polluted, and the problem is to prepare them for domestic use.

The question raised by this paper in regard to the previous treatment of the water is a bone of contention among scientists and sanitarians, and I feel that we cannot yet afford to unreservedly admit it as a fundamental method of purification. I believe the ideal methods will be those which are able to secure the purification of the water without the introduction of chemicals. They change the constitution of the water; they affect it for manufacturing as well as for domestic purposes, and they always, I think, put the medical profession of a community more or less in antagonism to the public authorities. On this basis I have always felt unwilling to promote the purification systems that provide for the use of chemicals. In private supplies, for instance, that of Girard College, where the medical control is under the complete control of the organization of the college, it is possible to establish a filter system, as has been done there, with the use of a coagulant, and to conduct it satisfactorily. The supply is not very large, and the management can regulate the operation as it pleases. Under such circumstances, a system of filtration has been installed

which has had a remarkable effect on purifying the water. Girard College is located in a district where the water is bad, as bad as in any part of Philadelphia, and I know that when in some laboratories in that district I draw the water for experiment, it is "distinctly visible" at a distance. Right in the midst of this district in which typhoid is prevalent, Girard College has escaped. In some views I showed here some time ago, dealing with the subject of typhoid, Girard College was shown in a plan of this district as being situated very much like an island, that is, with regard to typhoid statistics. Of the efficiency of the system there can be no question. It is a remover of microbes, and it is a means by which filtration can be made much more rapid. The results obtained at Lancaster and at other plants are those which would be expected from such a system, but the question in my mind is, whether we cannot do without the use of chemicals in filtration. These systems may be justifiable; I do not say they are necessarily dangerous, but I think they are, in a measure, not along the best line of development.

The author of the paper has challenged this view to a certain extent, and perhaps justly so. Nature may not always be operating to the best interests of the human being. The human being is only one of the many organisms that the world contains, and her processes are sometimes remarkably antagonistic, but this precipitating method has a degree of unnaturalness that perhaps, we ought to avoid. If we use chemicals they disturb the condition of the water, including its use as a manufacturing material. Manufacturers at Manayunk some years ago gave up the use of alum, which greatly increased the hardness of the scale in the boilers, by substituting a sulfate for a carbonate.

It has seemed to me, in looking over these processes, that if we want to introduce chemical methods it might be better to introduce them by chemical treatment of the water after the filtration, allowing the filtration to be rapid and capable in itself of removing all microbes. The chief danger from water is bacteria. This is a view widely exploited, so that we may safely take it as a point of argument. We can kill microbes by various methods. One of these methods is heat. If we could sterilize water by the direct action of heat on the water, we could kill the microbes. In order to furnish water to communities that shall be satisfactory, it must be practically clear and colorless. People will complain of water that is not clear and colorless, and processes that permit of the application of heat do not accomplish this change; they simply sterilize. It would be a possible and not at all a fantastic idea, by means of a heat exchange system, to practically kill the microbes by a heat filtration process which would remove most of the suspended matter and most of the color.

Another method, and one which was brought before this Club in a rather unwise way, is the "ozone" method. It has an advantage over the plans suggested in the paper in the fact that it does not introduce any chemical into the water in preliminary treatment. Ozone has a destructive action on most forms of mineral life, and the proper ozonization of water will render it practically sterile. The ozone, which is a modified form of oxygen, returning ultimately to the condition of oxygen, and it cannot result in any permanent changed condition.

We have heard about the copper-sulfate method, which is more or less objectionable, and it has been shown to be not by any means certain to kill

microbes of typhoid, as at first alleged. I still believe, however, that if we can get back to our established filtration systems based on that by which nature filters, we are on safe ground. Processes of filtration of water in nature are practically filtration through soil. It is generally accepted that we cannot depend upon purification by the flow of water in streams; there is no definite point at which a river will purify itself. Filtration through soil is an approved and natural process, and if we embody that principle in our filter-beds, we will, under proper conditions, accomplish a great deal.

The disposition of municipalities is to use too small an area for their filtration plants, and this probably accounts for the conditions in West Philadelphia. They have been trying to filter too fast, and the efficiency of the filters, as given to me a few weeks ago, in gallons, seemed rather high. The fact that they had cleaned one of the sand-beds a few days before and started to filter within twelve hours after the cleaning may be responsible for the condition. The figures, as published in the newspapers, of the amount of bacteria also seem rather high 320, 420, and so on—especially at this time of the year, when the number of bacteria is comparatively low.

We have a little too much dread of the microbes, and perhaps a little too much sensitiveness to what is called "the efficiency of filters." Personally, I believe, in regard to household filters, that if they will deliver a clear water, they will deliver a safe water. I have for many years had in my house a household filter which has delivered constantly, with reasonable care, a clear water, and I have never had the slightest reason to suppose that it has produced any infection. Persons other than myself, who have come from other parts, have used the water and never been in any way affected by it. I live in a district which has not been served with filtered water, but there is a comparatively low rate of typhoid fever, and most of the residents have filters of the proper class. The dangerous microbes get taken out by these filters, and it would be a very good thing if housekeepers generally were provided with filters of this class.

I have felt a little sorry that Philadelphia filtration matters have not moved a little faster. The proceedings generally have produced a lack of faith on the part of the public, and the recent agitation in the newspapers has, I think, added to this state of affairs.

John C. Trautwine, Jr.—Even to those who make a specialty of water supply, the *purification* of water is but one of many subjects claiming attention; but our author, with appalling exclusiveness, has devoted more than a quarter century to the study of this single branch. When such an authority favors us with his views respecting his specialty, our discussion should manifest a becoming modesty.

Nearly ten years ago, while the writer was Chief of the Bureau of Water of this city, the question of filtration had long been before the public, and was then under particularly active discussion.

About that time a member of the City Councils, who had been traveling in Europe and had seen our author's asbestos bag filters in use for the purification of small municipal supplies in France, described them to the writer and suggested the practicability of their employment for the purification of the water supply of Philadelphia.

The writer having already had sad experience of the vastness of the volumes

of water which the good people of Philadelphia insist upon passing into the sewers unused, could not help questioning the practicability of filtering these enormous quantities through small globular units, each about one foot in diameter, and he feels some satisfaction in the reflection that during our author's study and canvass of the matter as applied to the Philadelphia supply, the question of filtering through such small units has not been given extensive, if any, consideration.

A year or so later than the time mentioned, our author came to Philadelphia and fitted up a quite elaborate experimental plant at 1310 Arch Street, and the writer made frequent and interesting visits to this plant. He had also visited the preliminary filters designed by our author, and erected at Lower Roxborough and at Bethlehem.

The question of preliminary filtration first came to the writer's notice some ten years ago, in a pamphlet describing the system in use at Scheydam, in Holland.

The advantages and disadvantages (if any) of preliminary filtration seem to be somewhat analogous to those of compound and multiple expansion in connection with steam-engines. The earlier steam-engines effected all of the expansion in one cylinder, but modern developments have increased the number of cylinders to two or three or more, and it would seem but rational that the work of filtration should be divided between sedimentation, scrubbing, preliminary filtration, and final filtration, as suggested by our author, if indeed still further refinement is not eventually found economical, and therefore desirable.

Our author's comparison of the conditions obtaining at Lower and at Upper Roxborough is manifestly favorable to his argument in behalf of preliminary filtration, and it is to be regretted that we have not fuller information respecting the cost of the improvement evidently obtained through preliminary filtration.

Our author advises us as to the cost of scraping, transferring, washing, and restoring the sand, and as to "other expenses charged (not itemized)," but the sum of these he calls "total cost of maintenance and operation," leaving us under the impression that these figures do not include interest and depreciation on the preliminary filters.

With such information before us, it would have been practicable to determine whether the game was worth the candle; in other words, how nearly the same results might have been obtained at the same total cost by increasing the area of the slow sand filters.

Our author's substitution of well lighted rooms for what he calls the "catacombs" of the typical slow filtration plant, must appeal to the layman as a distinct advantage, and it would be interesting to learn from experience what compensating disadvantages, if any, are to be urged against the innovation.

The same observation applies to our author's use of a platform carried by a traveler running upon the side walls of the filter for the purpose of cleaning the bed, when such cleaning is required. It applies also to the glass tube communicating with the filtered water under the filter, and thus showing constantly the character of the effluent. Our author's method of washing the sand must also appeal to the layman as an improvement upon the usual methods, and the writer would be interested to hear what might be said to the contrary.

Our author informs us that, at Lancaster, "it was considered desirable not to change the chemical character of the water," and that therefore the reagents used "simply coagulate the fine suspended matter without making the water harder or softer." The location of Lancaster—in a limestone valley—would lead us to expect hard water in the Conestoga River, and, Lancaster being an important manufacturing town with many steam-boilers, soft water would seem to be a desideratum. The writer would therefore ask why the reagents used first, with a view to softening the water, were abandoned, and other reagents adopted which left the water "never more acid nor more alkaline after treatment than before"?

Most of us have been taught to believe implicitly in what our author calls "the biological idea," which teaches us that the "Schmutzdecke," which forms upon a filter-bed, is a battle-field in which the bacteria mutually destroy each other, and in which organic matter is oxidized, or "nitrified," as the experts (for some reason) call the process. It was with a feeling akin to shock that the writer learned, some years ago, that no less an authority than Mr. Hiram A. Mills, of Lawrence, Massachusetts, ventured to dissent from this doctrine. And now our author has the hardihood to refer to it as "pure romance."

Even laymen, however, nowadays require something more than an *ipse dixit* from their high priests, and the writer would have been glad to learn the reasons for our author's heresy respecting this generally accepted "biological idea." It no longer satisfies the inquiring mind of the layman to be asked to smile at the author's picture of the "cannibal-like bacteria whose propensity is to eat their weaker brethren," or to be told that "this is pure romance." If nature had been so constituted that her creatures could exist without destroying their weaker brethren, this *reductio ad absurdum* might have had some force.

Our author tells us that in the environment in which the bacteria find themselves when they are caught upon the filter-bed it is impossible for them to devour each other, and they have merely to lie still and die. But further on he tells us how microbes similarly caught upon the felt which formed his first water filter, made in 1879, "made short work of the wool" and discouraged him from further essays in that direction. Surely, if the imprisoned microbes can make short work of wool, it is hardly absurd to suppose that they may devour each other, as we human beings devour our fellow-creatures even though we may happen to be living under unsanitary conditions.

The writer submits also that our author is disingenuous in his argument against the "biological idea," that "algæ do not grow in covered filters," and that "if their presence was necessary to good filtration, their absence in covered filters would lead to bad results, which is not the case." If the writer understands the "biological idea," it contemplates, not an "algean jelly," but one in which bacteria are the active factors, and these, the writer understands, can operate as well in the dark as in the light. Our author therefore appears willing to make the biological idea ridiculous by showing the absurdity of a claim which the upholders of that idea do not make.

The writer, during his early acquaintance with the author and with his experiments in Arch Street, was much interested in the author's use of asbestos pulp which he mixed with the water in order that it might be deposited as a Schmutzdecke or blanket upon the surface of the filter-bed. This appeared to have the

double advantage (1) of hastening the formation of the Schmutzdecke, and (2) of facilitating the cleaning of the bed; for the asbestos pulp thus deposited cohered sufficiently to permit its removal very much as a sheet of wet blotting-paper would be removed. It was therefore a disappointment to the writer to be told by experts that the asbestos film thus deposited was open to the objection that air-bubbles formed under it.

The writer is therefore interested to learn that our author has substituted "fine charcoal and fine coke" for the asbestos of his earlier practice, but in the absence of information to the contrary takes it for granted that the particles of charcoal and of coke fail to unite in a continuous film, easy of removal, as the asbestos particles did.

In the early days, while filtration was under discussion in England, one of its objectors remarked that it was ridiculous to suppose that such treatment could do more than merely clarify the water, inasmuch as the microbes present in the water "could march a thousand abreast through the interstices left between the grains of sand."

Our author now gives us to understand that the real function of the Schmutzdecke, whether naturally deposited from the water or hastened by the use of coagulants or artificially produced, as by means of his asbestos or charcoal or coke, is not to provide a battle-ground where the bacteria destroy each other, but merely to form a trap in which these creatures are caught and permitted to die like flies upon "Tanglefoot."

The writer has always believed that in placing asphalt over the original clay and concrete linings of the Queen Lane and Roxborough reservoirs we were merely spreading a fine sieve over a coarser one, thus facilitating the capture and utilization of the fine particles carried in suspension in the water, which particles, thus caught, served to choke the passage and to prevent the further escape of water from the reservoirs, and our author's claim is that the Schmutzdecke in a filter-bed acts in a similar way upon the bacteria and in that way only.

Our author criticizes the statement that sand filtration is a natural process, or even an imitation of nature, and in support of his criticism points out certain differences between nature's method and that adopted by man. But when it is said that sand filtration is an imitation of nature it is hardly intended to assert that the imitation is perfect in all respects. On the contrary, filtrationists are apt to assert that artificial filtration is an *improvement* upon natural filtration—that man, in applying nature's methods, avoids the mistakes and limitations to which nature is necessarily subject. Our author says: "Nature's sand is not confined between walls. It has thousand of acres to do its work." Surely man has improved upon nature by getting a vastly higher efficiency out of his acres.

In discussing the rapid or so-called mechanical filter our author remarks that while a "mechanical" plant is relatively cheap in first cost, its cost of operation and maintenance is much greater than that of slow sand filters. It would be interesting to know how the two types compare in cost, summing up, in each case, the cost of construction and the capitalized cost of operation and maintenance.

Messrs. Rudolph Hering, Samuel M. Gray, and Joseph M. Wilson, the experts

called in to advise respecting our water supply in 1899, give, in their estimates, figures for the cost of operation, maintenance, interest, and depreciation, for rapid and for slow filtration, showing only about $4\frac{1}{2}$ per cent. difference in favor of slow filtration, on projects for furnishing 450 million gallons per day.

	Annual Cost of Operation, Maintenance, Interest, and Depreciation.
Rapid filtration:	
From the Delaware at Torresdale	$3,108,606
Slow filtration:	
150 million gallons per day from the Schuylkill,	
300 million gallons per day from the Delaware near the city	2,971,801
Difference in favor of slow filtration	$136,805

Among the many objections urged by our author against the "mechanical" system, he mentions "the increased amount of incrustating constituents in the water." The writer has been under the impression that where the raw water contains lime in sufficient quantities to effect the decomposition of the alum or alumina sulphate, the amount of incrustating constituents in the water is not increased.

Our author mentions the fact that certain metals dissolved in water are removed by filtration, while other metals, similarly dissolved, are not removed. The question of removal, by filtration, of dissolved impurities, has been so often brought to the writer's attention, that he ventures to suggest that this particular question might properly be made the subject of a short paper by the author. In stating that, with proper precautions, it is safe to expose filtered water to storage without protection by means of a roof, our author attacks another time-honored belief of filtrationists, and it is to be hoped that his statement will lead to further discussion of the question, and to the letting in of more light upon it.

His curious and interesting experience respecting the growth of algæ in the light and their discouragement by darkness, reminds the writer of the experience related by a Western engineer respecting a reservoir in that part of the country. His reservoir was covered with boards laid with narrow spaces between them, the boards and the spaces running from east to west so that the bands of daylight, sent into the water through the spaces, remained nearly constant in position throughout the day. Under these conditions there was considerable vegetable growth, but when the boards were replaced in a position running north and south, so that the bands of light, entering through the spaces between the boards, swept through the reservoir daily, from west to east, this growth disappeared.

The writer is disposed to take issue with the author's statement that soft water is better for all purposes. The writer has found it invariably inferior to hard water for rinsing soap from one's hands after washing them, and he ventures to say that any one who will make a comparison in this respect between the soft water supplied at Atlantic City, and the relatively hard water furnished from the Schuylkill in Philadelphia, will agree with him.

H. D. Fisher.—Very little has been said about sterilization. I have been working considerably along that line, and have found, apparently, that it is the only way to be absolutely sure of the purity of the water. Of course, it is too expensive a method for a city supply, but for household use it is practicable; that is, the apparatus can be run at a slight cost. Our experience has been that it is good to boil water all the time.

In 1898 there was a test of water-purifying apparatus at Washington, D. C., by a board of army officers, and this is part of the report: "Water Sterilizer: The foregoing apparatus has occupied considerable time on the part of the Board in carrying out the necessary tests of the same. As the result of numerous observations made with three styles of apparatus, we find that water heavily charged with the typhoid bacillus, the colon bacillus or the Bacillus prodigiosus, escapes from the apparatus entirely rid of living organisms. . . . Careful tests by Dr. W. M. Mew, Chemist of the Surgeon-General's Office, show that there is no loss of the natural gases during the passage of the water through this apparatus."

I may add that sterilization takes that rich, beefy flavor out of Schuylkill water.

"Water passing through this sterilizer, although brought to the boiling-point, is maintained at this temperature for so short a time as not to be deprived of its natural gases, and hence not rendered unacceptable to the taste. . . . All living micro-organisms, except a few spore-bearing bacteria, are destroyed by the degree of heat attained during the passage of the water through the apparatus. The disadvantage of the escape of a few spore-forming bacteria through this apparatus is considered to be of no practical importance by the Board. . . . As the result of the exhaustive experiments, the minute details of which it is not considered necessary to enter into in this report, the Board is of the opinion that the sterilizer is superior to all filters or other water sterilizers submitted for trial, and that it is well adapted for the abundant supply of sterile water to troops serving in the field. We, therefore, after a careful consideration of the requirements of S. O. No. 306, A. G. O., Washington, December 29, 1898, respectfully recommend that the Forbes Sterilizer be issued for the use of troops serving in the field."

The Board was composed of the following officers: President, Walter Reed, Major and Surgeon, U. S. A.; E. O. Shakespeare, Major and Surgeon, U. S. V.; Victor C. Vaughn, Major and Surgeon, U. S. V.

The report was made after severe and exhaustive tests, extending over six months, of upward of thirty competing devices for filtering or otherwise purifying water.

The cost of sterilizing water in large quantities would probably be in the neighborhood of $40.00 or $50.00 per million gallons, including all charges.

In the island of Panay in the Philippines a body of soldiers were stationed on a mountain 6000 feet high in the interior and supplied with perfectly clear water from a watershed entirely free from human contamination. In spite of this the surgeon required all water to be sterilized, and the sickness was about 3 per cent. This surgeon was recalled and another sent out who discontinued the use of the sterilizers, and inside of six weeks 75 per cent. of the men, and the surgeon himself, were down with intestinal troubles. Another surgeon

was sent out, and on resuming the use of the sterilizer the sickness went back to about 3 per cent. as before.

J. W. Ledoux.—The author has presented to the Engineers' Club a paper containing much valuable data and suggestions. He has shown us that double filtration, first by a rapid and coarse strainer process, and second by a fine and slow straining process, will produce as good results as can be obtained by the much more rapid and general process with the aid of a coagulant, known as mechanical filtration, or by the much slower process known as sand filtration.

It is too bad that in a paper so valuable as this it is necessary to resort to the methods of trade publications to present the strong parts of their own devices and the weak parts of others. In fact, one unfamiliar with the art would suspect from certain portions of the paper that, with the exception of these designed by the author, all common types of slow sand and mechanical filter plants were failures. Mention is made of the large typhoid rate in Atlanta, Ga., and Norfolk, Va., to show that the mechanical type of filters in these places had failed, when, as a matter of fact, it is entirely probable that the water supply had absolutely nothing to do with the increase of typhoid fever during the periods mentioned.

The Chattahoochee River, which supplies Atlanta, drains an area of about 1600 square miles of barren, sparsely inhabited, and poorly cultivated territory having a great deal of wooded area. There is some mining going on near the head-waters of the stream, but the contamination from these sources is probably immaterial, and it was only necessary to filter the water because of its high content of turbidity, due to the washings of the red clay hills so prevalent in the gneissic regions of the South.

At Norfolk, Va., the water supply is taken from Little Creek, which has a drainage area of about eighteen square miles, composed of flat lands largely wooded, and not very highly cultivated. The population is sparse, and at no point are there more than three or four houses close together. The storage reservoir is very large, containing over two thousand million gallons. It is entirely likely that the water supply had nothing to do with the increase of typhoid fever, and the principal reason for putting in the filter plant was to reduce the high color and remove as much as possible the vegetable matter and consequent swampy taste and odor.

There is a great deal written about the relation between the water supply and the typhoid death-rate, but in many cases, like the two just mentioned, it is entirely probable that they are not in any sense related.

No doubt the author could, if he would, present data showing that the operations of his filter plants had been frequently unsuccessful. Take the case of Lancaster, Pa. When the city was receiving propositions, the Maignen system of filtration was more popular than any other system of mechanical filtration because no coagulants were required, and no doubt a majority of the people believed that it would not be necessary to use coagulants, while subsequent conditions have proved them so essential. I would suspect from the author's statement that the early results were not at all satisfactory, to overcome which it was necessary to introduce the principles of mechanical filtration, using sulphate of alumina as a coagulant and soda ash to neutralize the permanent hardness imparted by the sulphate of alumina. This is an old device and in use

in a number of places, but usually lime is found to be cheaper and in many cases more satisfactory than soda. To use enough, however, to soften such water as the Conestoga River is an entirely different proposition, and presumably the author had no intention of carrying his process to that extent.

At Charleston, S. C., where it required three grains of sulphate of alumina per gallon to reduce the color from 200 to 10 parts per million, it was nearly always necessary to use either soda ash or lime to produce sufficient alkalinity to decompose the sulphate of alumina, but at the Lancaster plant evidently the soda ash was not used for that purpose, but, as before stated, to restore the water to the same degree of hardness that it was before filtration. The Conestoga water is a limestone water, and therefore considerably harder than should be desirable in that section of the country.

Regarding the process of washing in mechanical filtration; the author states that the filter attendant knows that the filter needs washing only by reason of the dirt coming through. That might be true where the sand grains are very large in size, or in some methods of operating the filters whereby an overdose of coagulant is introduced in the beginning of filtration; but our practice is that the need for washing the filters depends on the rise in pressure or loss of head. For instance, in gravity mechanical filtration the loss of head may get as high as 10 feet or 12 feet, while in pressure mechanical filtration the loss of head may go as high as 50 feet; while in each case the filters are giving their maximum degree of purification.

The author shows in his filters under-drains consisting of a section similar to what would be produced by splitting a pipe longitudinally and made so as to rest on the floor, and having adjacent to this floor a series of rectangular slots, requiring much less fine gravel, and reducing the necessary thickness of the bed of filtering material; but by placing the drains closer together there is much less tendency to short-circuit the water-currents. In Europe, and in a few well designed plants in America, the under-drains consist of a row of bricks set on their edges and spaced several inches apart, and resting on the top of these another layer of bricks laid on their flats and touching each other. The lower course connects with the central drain. This is an excellent plan and much more expensive than the plan above referred to. Evidently thin concrete blocks can be used instead of bricks.

In regard to sand washing for slow sand filters or those referred to by the author, experience has shown that the "jet" is as efficient an apparatus as can be devised, and the fact that this method is almost universally used in Europe and in the best slow sand filters of America is further evidence of its efficiency. There is no necessity of the fine sand being lost, and it will not if the waste water carrying off the dirt passes out at a low velocity.

It has been stated during the discussion of this paper that in the design of a filter plant the nearer nature can be copied the more likely we are to have good results. By this is undoubtedly meant that if water could be obtained in sufficient quantity and of as good quality as contained in the wells of our early days, the water purification problem would be solved. It is seldom that shallow well-water is obtained where there is less than 50 or 100 feet of soil between any source of contamination and the well; so that these would at first sight have a great advantage over a sand filter where there is only three or

four feet of sand. To copy the well method, assuming that we have a contaminated river, it would be only necessary to dig a large basin having sufficient percolating area, and then pump the river-water into the basin. Then around the basin, within 100 feet or so, sink wells so that they will intercept the water percolating from the bottom and sides of the basin. No doubt this plan would be very satisfactory for some time, but if the river-water is badly contaminated I believe the wells will eventually become contaminated also. This is proved by the fact that in a newly settled area wells frequently furnish a good pure soft water, and after the population is increased to two or three hundred the wells will, in the course of a few years, become foul and hard, and finally typhoid fever will become prevalent. This proves that it is not safe to depend on the continuous purifying effects of a considerable thickness of soil. Undoubtedly there is a thickness sufficiently great for safety, but this thickness may be measured in miles instead of feet.

Cities should adopt the purest water supply possible to get, even if it taxes their financial resources to the utmost, and if this water is not good enough it can be filtered, as it is safer to depend on a good supply filtered than a poor one. In looking over some of the large towns in the United States, and especially Pennsylvania, it would seem that the opposite policy has been adopted. In several instances supplies of pure, practically uncontaminated water could have been obtained by gravity within a reasonable distance, but instead of adopting these supplies the cities have taken water from sources little better than open sewers, and then depend upon subsequent filtration to make the water fit to use.

G. Edward Smith.—It is possible that the intestinal disorders occurring in filtered water districts are caused by germs that had impregnated the lining of the old water pipes when they were used for raw water, and that had subsequently been taken up by the filtered water. Referring to the great waste of filtered water alluded to by Mr. Trautwine, it is probable that if meters were generally used the reduced consumption would result in better filtered water.

Mr. Mebus.—There is no objection to either sterilization or household filtration, if properly done. The fact is, however, that people, through lack of appreciation of the danger of using raw water, or through indifference or indolence, will not go to the trouble of boiling or filtering the drinking water.

People of large communities expect everything supplied to them in a perfect state—for example, as is gas and electricity. The public health is therefore not as well safeguarded by dependence on individual efforts of purification as by having the entire public water supply purified under proper scientific supervision.

Wm. Easby, Jr.—The paper states that the beds of a filter plant should not be as large as those commonly used because the resistance in the under-drains causes a non-uniform rate of filtration in different parts of the bed. In a well-designed plant this resistance is about 20 per cent. of the resistance in the clean sand-bed, but shortly after a bed is put in operation it becomes insignificant in comparison to the resistance in the surface coating. Variation in the rates of filtration is more largely due to non-uniformity in the grade of the sand and its compactness in the bed. Such a restriction in the size of beds as that suggested would increase the cost of construction.

P. A. MAIGNEN.—The author has to thank the speakers of the evening for the very kind manner in which they have treated his paper. He agrees with Dr. Leffmann that the "ideal methods will be those which are able to secure the purification of the water without the introduction of chemicals." This is precisely what is done at South Bethlehem He also agrees with him, with the medical profession, and with the public authorities when they object to chemical treatments which make or may make the water chemically worse after treatment than before.

He would strongly object to drinking-water which had been sterilized by any of the following compounds, which have been seriously proposed in Europe during the last ten years:

Add to the water three tablets composed of the following substances: 1st tablet—iodid of potassium, iodid of sodium, methylene-blue; 2d tablet—tartaric acid, sulfofuschine; 3d tablet—hyposulfite of soda (Vaillard).

Chlorid of lime and sulfite of soda (Traube).

Peroxid of chlorin (Berge).

Chlorid of lime and perchlorid of iron (Duyk).

Bromid of potassium and ammonia (Schumburg).

The author, it will be remembered, has shown in his paper that Dr. Burlureaux and himself, as far back as 1890, established the fact that water softened with plain reagents such as lime and soda is at the same time sterilized without being injured in any way in taste or quality.

The hard water of Canterbury and Southampton in England has been softened for years with lime, and no one has ever complained. The City of Columbus, Ohio, is going to soften all its water supply. There are in Europe thousands of water-softening plants, not only for industrial water but also for drinking-water, and these are doing most excellent work.

The water to which alum is added on its way to house filters is rendered hard and unsuitable for drinking. The devices in which the alum is placed and from which the solution flows into the stream of raw water going to the filter are frequently defective. Sometimes the valves that proportionate the alum solution to the applied water are opened more than they ought to be, and an excess of the chemical is applied and goes right through the filter, passing out undecomposed. Such water is extremely unpleasant for bathing and washing, for it does not lather, and taken with food it curdles it and renders digestion difficult.

Dr. Leffmann has pointed out one of the most serious objections to the use of alum in the chemical treatment of water, namely, the transformation of the "temporary" hardness (due to bicarbonate of lime, which precipitates as mud in the boilers) into "permanent" hardness (due to sulphate of lime, which makes a "porcelain" scale). He suggests that if chemicals are to be used they should be introduced in the water after filtration. This would not do at Lancaster. Here the object of the chemical treatment, as at present carried on, is not to modify the (chemical) quality of the water, nor to sterilize it. It is intended to coagulate the very fine particles of clay, which are in the water in immense quantities in times of flood, and to deposit them in settling tanks previous to filtration and thus avoid putting, at such times, any undue strain

on the filters proper. The chemical treatment has been used at Lancaster twenty-two days out of fifty-six in which the water was very heavily charged with mud. It is not likely to be resorted to more than sixty or sixty-five days out of three hundred and sixty-five.

Referring to ozonization, it will be remembered that when one of the ozone processes was presented to the Club the author of the paper was asked what was the cost of the treatment, and he gave no answer. We find in the "Municipal Journal and Engineer" of October 3, 1906, the following information: "Dr. Miquel reports that the process (Frize) has been found capable of eliminating a large proportion of the bacteria present in water of various descriptions, and of permanently destroying with certainty the bacillus coli, which possesses greater resisting power than the Eberth bacillus and the cholera spirillum. The cost of this treatment is stated, in dealing with large volumes, to be about 1½ centimes per cubic meter, say 1½ cents per 1000 gallons" (fifteen dollars per million gallons). It has been stated that water intended for ozonization need not be perfectly filtered before the electric treatment is applied—that it is sufficient to filter it roughly. This is an error. Rough filters that cannot remove more than 50 per cent. of the suspended matter cannot, in times of flood, make the water clear enough to be acceptable to the public. Ozonization, which agitates it, does not make it clear. If there be any appreciable quantity of suspended or dissolved organic matter in the water to which the process is applied, a considerable quantity of "ozone" is absorbed or neutralized (by this organic matter) before the process can have any effect on the bacteria. An imperfectly filtered water therefore is much more costly to ozonize than a well filtered water. All that can be stated at this time concerning ozonization is that it appears to be too costly for the amount of work it does. The same result can be obtained by other processes which are cheaper. The electrical treatment therefore does not seem to have reached the stage of a practical proposition for application to large water supplies.

Mr. Trautwine asks for information concerning the cost of preliminary filtration. If he will turn to the author's paper on "The Lower Roxborough Preliminary Filters," published in the "Proceedings of the Engineers' Club" under date of April 16, 1904, he will find a full answer to the question. But for those who may not be able to consult these Proceedings it may be interesting to give here an example of the economy obtained by preliminary filtration.

Operation.—The cost of operation of slow sand filters is estimated to vary from $3.00 to $5.00 per million gallons filtered. For our present purpose we will take $3.00 as the cost.

The operation of preliminary filters is calculated not to exceed 75 cents per million gallons.

Fixed Charges.—The installation of slow sand filters costs from $30,000 to $60,000 per million gallons daily capacity. For our present purpose we will take the lowest estimate of $30,000 and count the interest and depreciation at 5 per cent.

The cost of installation of preliminary filters may be estimated at $6,000 per million gallons daily capacity.

When the water is treated by the plain slow sand filters alone we have:

Operation.................................... $3.00 per million gal.

Fixed charges,—interest and depreciation on filters ... $\frac{\$30,000 \times 5}{365 \text{ M. G. } 100} = \$4.10$ per million gal.

$7.10

When it is treated by the double process of scrubbing and filtering, and if we assume that 60 per cent. of the work is done by the scrubbers, we have:

Operation:

60 per cent. of the work	@ $0.75=$0.45		
40 per cent. of the work	@ $3.00=$1.20		
		$1.65	

Fixed Charges,—interest, and depreciation on scrubbers $\frac{\$6000 \times 5}{365 \text{ M. G. } 100} = \$0.82$ per million gal.

The total cost of the double process therefore is:

60 per cent. of the work	@ $0.82=$0.49		
40 per cent. of the work	@ $4.10=$1.64		
		$2.13	$3.78

Economy due to the use of preliminary filtration, per million gallons.. $3.32

For a plant dealing with:

10,000,000 gallons daily, the yearly economy would be $12,118.00
20,000,000 gallons daily, the yearly economy would be 24,236.00
40,000,000 gallons daily, the yearly economy would be 48,472.00
100,000,000 gallons daily, the yearly economy would be 121,180.00

Mr. Trautwine says "our author appears willing to make the 'biological idea' ridiculous by showing the absurdity of the claim which the upholders of that idea do not make." Let us see whether the author has been guilty or foolish enough to fight a phantom. In Mr. Trautwine's speech we find that the "biological idea" is represented somewhat in this wise: "The bacteria devour each other as we human beings devour our fellow-creatures." "The 'biological idea' teaches us that the Schmutzdecke which forms upon the filter bed is a battle-field in which the bacteria mutually devour each other." Now, this is exactly the idea which the author believes has not been substantiated. The bacteria ate the wool, they did not eat one another. In sand filters they cannot eat the silica.

Micro-organisms seem to have been created for the specific purpose of decomposing the albuminous matter of dead plants and dead animals. Cannibals are as rare among bacteria as among men. Place a freshly cut rose or any other flower, a piece of straw, or a small bundle of hay in a jar containing pure water. Look at a drop of this water through a microscope a fortnight afterward. You will see two or three kinds of animalcules of the protozoan order, which are classed as animals. They have some of the peculiarities of fish and some of the habits of rats and pigs. They live on the diminutive garbage which is in the water. Introduce a piece of meat in pure water; look at a drop of this water under the microscope in a week's time (the infusion being kept at room temperature). You will find an innumerable number of exceedingly small active organisms.

Two or three weeks later these small organisms will have disappeared and their place will have been taken by larger and more active organisms, and you can judge by their apparently intelligent movements that they aré engaged in the serious business of decomposing the organic matter into gas, water, and earth, with the production sometimes of toxins or other by-products. You will not see them eat one another.

Take another instance—that of alcoholic fermentation in wine, cider, or beer. Here we have a species of organism of the yeast cell class known as saccharomyces ellipsoideus. The wine ferment is egg-shaped; its business appears to be confined to eating the sugar and transforming it into carbonic acid and alcohol. As long as there is any sugar in the solution the alcoholic ferments grow and multiply with such vim that they leave no room for any other kind of micro-organisms, but when all the sugar is consumed the saccharomyces organisms become decrepit and fall to the bottom of the vessel, constituting what is known as "lees" or dregs. If the wine thus fermented is clarified and deprived of all sediment after this first fermentation and placed in vessels free from water or other impurities, it will keep a number of years without any further decomposition. But if it is left to itself, if the air has access to it, if the cask in which it is stored is not strictly clean, a second kind of organism, the micoderma aceti, takes hold of the wine and turns it into vinegar. This organism is grape-shaped in form, and under favorable conditions of temperature it increases so plentifully as to practically occupy all the available space. Sometimes, particularly when the grape juice contains leaves, stalks, and dirt, the secondary fermentation, instead of being acetic, is caused by putrid ferments of the same order as those which create putrid fermentation in water. The wine becomes "sick" or "ropy," and if left to itself undergoes a series of successive fermentations until it is converted into water and earth. The organism which causes the sickness in wine is of a filamentous appearance, a bacillus. While this putrid fermentation is going on, you see one kind of organism prevailing at one time and another kind at another time. As far as the author knows, they do not eat one another, they live the natural span of their allotted life, and when the appropriate food is all consumed they die, giving place sometimes to other kinds with different tastes, and these also in the end die out unless they are transferred into pastures new.

How Long Do Typhoid Germs Live In Water?—You will remember the table presented by the author showing that typhoid bacilli die in distilled water in a short time. Is it because they do not find appropriate food in the distilled water? Or it may be that the distilled water itself is impure and contains dissolved metallic salts absorbed from the glass or metallic vessels in which it is distilled or stored. The question remains open.

We have often been told that typhoid bacilli are destroyed by the ordinary water bacteria, and now Mr. S. J. Lewis, in the paper already alluded to, tells us that the bacillus of typhoid fever conquers the water bacteria. The full text of Mr. Lewis' paper is as follows—(U. S. Geological Survey, Paper No. 161, page 75):

"The anthrax bacillus and its spores, the staphylococcus pyogenes aureus (the organism of pus) and the typhoid bacillus can retain their life a very long time in water. Karondi found that the ordinary water bacteria multiplied

greatly for a time after the introduction of the pathogenic organisms and then began to die out, and that for varying periods the foul water, being kept at room temperature, was found to contain pure culture of the disease-producing organisms which retained full virulence up to complete evaporation. For the anthrax bacillus and its spores the period of life varied from 264 to 816 days, the water bacteria in the medium having completely disappeared after three or four weeks. The pus organism was found in pure culture after two months and retained its virulence for 508 days. The bacillus of typhoid fever showed similar power of *conquering* the water bacteria which lived in the medium for four months, at the end of which time the bacillus typhosus was in pure culture, living in ordinary tap water at room temperature for 499 days. What more evidence is needed of the ability of the organisms of water-borne disease to poison a water as far as drinking purposes are concerned for a long time, admitting the pollution to cease instead of continuing as in the cases under consideration?"

The author thinks that the word "outliving" would be more appropriate than the word "conquering" used above.

Typhoid Not Always Due to Pre-existing Cases.—There is just now a great controversy about typhoid fever. We are told that during the present year there has been a great wave of typhoid throughout the country. Certain cities which have modern filter plants have been seriously afflicted and attention has been drawn to what is called "residual causes," such as milk, fruit, vegetables, and wells. But while we acknowledge that these "residual" causes may account for stray cases, epidemics are always due to water pollution. It is thought that this pollution must necessarily come from sewage containing the specific germs issued from typhoid patients. While we are not prepared to deny this theory, we ought not to shut our eyes to the fact that sporadic cases may also occur without pre-existing cases; thus, the infection may come from the decomposition of animals drowned in wells, or from vegetable or animal matter decaying in pools, ditches, and swamps. The bacteria bred in these stagnant waters may easily find their way in flood times into the water-courses. Typhoid and all intestinal disorders are practically filth diseases. Water supplies which are sometimes said to be above suspicion may all of a sudden become infected by filth, as at Plymouth, Pa., and as is probably the case now at Scranton, Pa. It may, therefore, be laid down as an obligation on the part of municipalities to see to it that all the water supplies be carefully purified, and it behooves every householder to make sure that the water used by the family is purified at home. Although the water of London is filtered by the municipality, there is hardly a house in the great metropolis without some sort of domestic filter.

The estimate of Messrs. Hering, Gray and Wilson comparing the cost of mechanical and of slow sand filtration and showing that there is very little difference between the estimated total cost of the two systems—fixed charges and maintenance—is true of most other estimates, but as a general proposition if the depreciation is taken into serious consideration the mechanical system is likely to be the more costly in the long run.

Referring to the so-called "English" or plain slow sand filters, we often hear it said that they are good enough to be copied without being improved upon. It should be stated in a discussion of this kind that they have not always been

perfect. Thus, Mr. Ripley Nichols, in his book entitled "Water Supply" (page 159), gives the following table showing the efficiency of the London slow sand filters:

TABLE XXII.—THAMES AND LEA WATER.—COMPARATIVE EFFICIENCY OF DIFFERENT RATES OF FILTRATION DURING THE YEARS 1868 TO 1873, INCLUSIVE.

Name of Company.	Maximum Rate of Filtration Expressed in Inches per Hour.	Number of Monthly Occasions When:			
		Clear.	Slightly turbid.	Turbid.	Very Turbid.
Thames:					
Chelsea..................	7.27	49	15	5	6
West Middlesex...........	4.71	75	0	0	0
Southwark and Vauxhall ..	6.00	41	24	5	4
Grand Junction...........	6.97	55	14	7	0
Lambeth..................	12.00	42	11	12	10
Lea:					
New River...............	5.00	70	4	0	0
East London.............	3.85	51	18	3	2

It will be observed in this table that the West Middlesex Company has had clear water all the time. This is due to two factors: The water of the Company was taken at a higher point up the Thames River than that of the other companies, and in addition it was (if the author remembers correctly) made to pass into gravelly soil—after the fashion of filter galleries—before reaching the filters proper. The New River Company made a better showing than the East London Company, because it also takes its supply much closer to the source of the River Lea. As a general rule, the water intended to go through the London filters is stored in large sedimentation reservoirs, which have sometimes been called "stagnant pools," and in which, in the summer, weeds and algæ grow to a very great extent under the influence of the sunlight. These algæ die after a cloudy or rainy day and give a bad taste to the water. In the spawning season the fish spawn comes to the filters in such quantity as to clog them sometimes in a few hours. The London companies, as the author understands, are now trying preliminary filtration to help their plain slow sand filters.

In a report on "Filter Tests," made by Dr. Med. Karl Schreiber, of Berlin, we read the following observations concerning the sand washing operation: "Rapid filtration possesses a great advantage as compared with slow sand filtration in the method of washing. For this purpose in slow sand filtration workmen must enter the filter. The sand is generally transported outside in wheelbarrows, and during this, as well as during washing and during the transportation back to the filter, it comes into contact with the hands and the dress of the workmen. In winter this process of cleaning may not be required for months, while in summer it may become necessary very frequently, in consequence of which a sudden increase of the working force may be required, and it may then not always be possible to examine the men in regard to their health, which circumstance certainly involves the danger of an infection, es-

pecially during an epidemic. In a rapid filter plant, however, washing is done entirely mechanically; the workmen do not come into any contact whatever with the filter bed or with the water." The author must confess that "the contact of the sand with the hands and dress of the workmen" does not appear to be so great a danger as is suggested by the Berlin critic.

We find in the same report the following statement: "In case a rapid filter plant should happen to become infected by pathogenic germs, then a disinfection of the entire plant by sterilization can readily be made at a small cost. In slow sand filtration the filters cover so large a space that this in itself would make disinfection very difficult."

Are we to understand that the mechanical or the slow sand filters intended to furnish cities with pure drinking-water can, at any time, become infected—that the germs of disease which they retain at one time can be given back to the water at another? What a disillusion this must be for those who think that these large municipal filters are absolutely safe methods of protection against water-borne diseases! The fact is that the danger in question does exist. We can conceive of large plain slow sand filters being so constructed and operated as to be liable to infection, but we also know that they can be designed so as to remain perfectly safe at all times, and one of the best means to bring about this safe condition is to prepare the water as thoroughly as possible by such method as preliminary filtration before admission to the final slow sand filters. The management of mechanical filters may be of such superior kind as to give safe water all the time, but the author must confess that this is a very difficult thing. If the chemical reaction or sterilization is not complete the filtration cannot make the water safe. One of the best ways to improve the work of the mechanical filters would be to subject the water to preliminary filtration previous to final rapid filtration so as to avoid the necessity of frequent cleaning, which, as has been explained, is the bane of the system, not only in matter of cost but also in matter of efficiency.

Another record in favor of double filtration comes from Kittanning, Pa., where a double semi-rapid filter plant was erected upon the design of the author and placed in service on February 19, 1905. The following is the report of the local Board of Health:

1904	103 cases	8 deaths
1905	25 "	2 "
1906	8 "	0 "

Mr. Trautwine finds fault with the soft water of Atlantic City, and with soft water in general because he says he cannot wash the soap off his hands. Accustomed as he is to make a liberal use of soap with hard water, it is evident that he uses too much soap with the soft water. He should use less soap and he would require less water to rinse it off. The English ladies are very fond of soft water because it enables them to use very little soap.

Mr. Trautwine asks why the reagents used first at Lancaster (with a view of softening the water) were abandoned and other reagents substituted. The author replies: because the people of Lancaster were not ripe for the improvement. To tell the people of that city, and particularly the fault-finders, that it would be better for them if the Conestoga water were softened, would be like

telling Mr. Trautwine that soft water is better for rinsing soap off the hands than hard water. Any change in the chemical composition of the water was looked upon by the authorities as courting discussion. The yellow journals were continually on the lookout for anything that might discredit the administration which had presided over the installation of the filter plant. One day a local druggist rushed to the Mayor's office with a bottle of water in which he said he had detected alum. Mysterious whisperings went through the ranks of the opposition leaders; the filter plant had been detected at fault. What joy!

Upon investigation it was found:

1. That no chemicals of any description had been used at the filter plant for more than three weeks previous to the collection of the suspected sample.

2. The local druggist had added ammonia to the water as a reagent and had obtained thereby a flocculent precipitate which he at once labeled alum.

3. The sample was submitted to Dr. Samuel P. Sadtler and son, of Philadelphia, who pronounced the precipitate to be due, not to alum, but to magnesia—one of the natural constituents of the Conestoga water.

When the question of chemical purification of the water was being considered by the administration of Lancaster it was thought undesirable to change its chemical quality in any way. It was suggested that the people were accustomed to the Conestoga water "nature" with its lime and magnesia, and that any change, even for the better, would be found fault with. This is why the water-softening process was not persevered in and the treatment was limited to a purely physical coagulation. The author has no doubt that before very long the advantages of soft water will dawn on the good people of Lancaster and that the softening treatment will be ultimately called for.

In this connection we find in the U. S. Geological Survey, Paper No. 161, sentences like the following: "The quality of the water is fairly good for drinking purposes, though too high in mineral matters for commercial use." "These waters are all hard rock water suitable for drinking purposes but high in incrustating and corroding solids and therefore unfit for use in boilers." The able geologist is somewhat at fault in things physiological. Hard water is never good for drinking. If it is capable of making incrustations in boilers it also makes incrustations in animal articulations. This has been clearly established in Europe for years. "Waters which contain lime or other mineral salts which are not naturally in the organism," says the Sixth International Pharmaceutical Congress, Brussels, 1888, "form, with the chyle, an abnormal medium for hematosis (formation of blood). They fatigue the kidneys and incrust the articulations."

Artificial Filtering Membrane.—Mr. Trautwine "has been informed by experts that the asbestos film (deposited on the sand) was open to the objection that air-bubbles formed under it," and he takes it for granted "that the particles of charcoal and of coke fail to unite in a continuous film, easy of removal, as the asbestos particles did." In his experiments with asbestos the author has not been much disturbed by air. This phenomenon of air-bubbles occurs mostly within a few days or a few weeks of placing the filter in service for the first time. Afterward it does not occur. Although the charcoal or coke powder cannot be rolled like an asbestos blanket, it is as easily removed from the sand as

ordinary mud, and therefore it does not offer any difficulty in operation or in cost.

Natural Filtration.—Under the generic title "natural filtration" Mr. Lewis includes "filter wells," "filter galleries," and "filter cribs." He describes the filter wells in use at Monongahela, Braddock, and other West Virginia towns; the filter galleries established at Woburn, Mass., Lowell, Mass., Indianapolis, Ind., Columbus and Springfield, Ohio; the filter cribs of Montrose, Pa., Tarentum, Pa., Hulton, Pa., Sharpsburg, Pa., Etna, Pa., Milvale, Pa., and Wildwood, Pa., etc.

The "filter wells" are generally about 20×20 feet. They are sunk at a little distance from the river (30 feet at Braddock). The water of the running stream is supposed to seep through the sand and gravel of its own bed and pass into the well. In no case have the results been satisfactory. At Braddock, for instance, there were in 1900 one hundred cases of typhoid fever in a population of 16,654.

Filter galleries are open drains laid in gravelly soil into which river-water or ground-water penetrates and from which it is drawn or pumped, and the water so filtered is supposed to be purified. Mr. Lewis says: "The filtration in filter galleries only clears the water of visible impurities, frequently making it doubly dangerous by masking the pollution. The device, when successful, is merely a form of well that has much greater collecting surface than the ordinary well can have, collecting ground-water in the same way as an ordinary shallow well and subject to the same contamination from accidental pollution." All the filter galleries described by Mr. Lewis have practically failed to give good water.

Filter cribs have had no better success. The bacterial analyses of the water drawn from the cribs show, if anything, an increase in the number of germs as compared with the river-water which it was intended to purify. The crib of Montrose is 2,500 feet long, 32 feet wide, 7 feet deep, its framework having been built of 6-inch×8-inch hemlock timbers laid flat. The timbers are spread by blocks 4 inches thick, spaced about 3 feet apart. It is tightly planked over on top with 3-inch planks, but its sides and bottom are open. In placing the crib an excavation somewhat larger than the area of the structure was made and the crib was floated over and sunk into place. It is covered with stones and coarse gravel with sand on top. The average depth of gravel and sand on the crib is 5 feet. The depth of the crib below surface at low water is 16 feet at the upper end and 10 feet at the lower.

In all these so-called systems of natural filtration—wells, galleries, cribs—the filtration goes on finely for some hours, days, weeks, or months, but if the applied water be at all roily the sand and gravel soon become saturated or clogged with mud, then either the water ceases to come through, or, if it does come through, it is not filtered. It passes in fissures, "rat holes," or open channels, which have no more effect in purifying water than plain cast-iron pipes. It is easy enough to separate mud from water by filtration, but it is not a simple matter to remove the mud from the materials which have collected it. It is difficult enough with slow sand filters and with mechanical filters, but it is altogether impossible with filter wells, filter galleries, or filter cribs. Such devices, therefore, are nothing but a delusion and a snare.

Mr. Fisher has described an apparatus called water sterilizer. The principal advantage claimed for this apparatus over the ordinary methods of boiling water is that it "can be run at a small cost" for fuel, owing to the exchange of heat units between the incoming cold water and the outgoing hot water, and that the water cannot get out of the apparatus unless it has been raised to the boiling-point. According to the report quoted by Mr. Fisher, "the living organisms are destroyed" by boiling, but "the spore-bearing bacteria are not destroyed by the degree of heat (212° F.) attained during the passage of the water through the apparatus." The French and German sterilizers based upon the same exchange system keep the water during a few minutes at a temperature of 120° C. (248° F.), and this is supposed to kill the spore-bearing bacteria. Prof. Tyndal years ago demonstrated that to sterilize water it was necessary to boil it three times on three subsequent occasions, allowing several days to elapse between each boiling. The spores or dry germs are heated and wetted during the process and presumably incubated, developing finally into adult or living bacteria. In this advanced stage of existence they are easily killed by boiling. A report presented to the French Académie des Sciences on February 19, 1906, by Messrs. Calmette and Breton shows that animals (guinea-pigs) were seriously affected by being made to drink or by being inoculated with water which had been polluted with tubercle bacilli and boiled. The animals previously weak were killed, and others, until then healthy, were made sick, with all the symptoms of tuberculosis. This finding has caused some French technical papers to say, "What is the use of boiling the water if the bacilli are not less dangerous dead than alive?" No explanation of this persistence of the danger in boiled water has been given. We may, therefore, suppose three things: (1) it may be that the simple boiling does not destroy all the bacilli, or (2) that it does not decompose or neutralize the dissolved "toxins," (3) or that the harm may be done by what is known as "fixed" toxins which remain in or on the body of the bacilli after boiling.

Mr. Ledoux says: "It is too bad . . . that the author . . . had to resort to the methods of trade publications to present the strong parts of their own devices and the weak parts of others."

Is it a crime to be prejudiced in favor of one's own inventions? The author does not hesitate to say that he is strongly in favor of slow sand filtration, which he has studied particularly during the last ten years. Will Mr. Ledoux deny that he also is prejudiced in favor of mechanical filtration, which he has improved and used in numerous waterworks for which he is engineer?

The author is not conscious of having been unfair to any person or system. He has not stated that "all common types of slow sand and mechanical filter plants were failures." He said that some (not all) of the slow sand filters and some (not all) of the mechanical filters had at certain times failed to give the results expected.

The author is not the only one nor the first to point out that "common types of slow sand and mechanical filter plants" were not always a success. Thus, for instance, Mr. Geo. W. Fuller, in "Transactions of the American Society of Civil Engineers," vol. l, 1903, page 471, says: "While, as is well known, in the majority of cases, mechanical filters have not been operated in a manner to produce uniformly good results, it is a fact, which does not seem to be appre-

ciated by many, that the majority of the larger sand filters in this country that have been operated for several years have also failed to reach the goal which may be expected of them, as is noted by any one who takes the trouble to examine carefully the typhoid fever experiences in cities which have sand filters, such as Poughkeepsie, Hudson, and Little Falls, N. Y., Ashland, Wis., Rock Island, Ill., etc."

The author endeavored in his original paper to avoid saying anything unkind of mechanical filters; he simply wished to draw attention to the fact that the water filtered during the first half hour after washing ought to be wasted, and even this he mentioned only because some engineers have suggested that it would not materially lower the average effluent if mixed with the filtrate of other filters and that therefore it should not be wasted.

Mr. Ledoux having entered on the war-path in favor of mechanical filtration, the author is bound to refer to various statements which may help to establish the truth. The allusion to Atlanta and Norfolk is to be found in the "Engineering News," November 8, 1906, in the paper of Mr. Theodore Horton, who says: "The cases of typhoid fever during July, August, and September, 1906, were more than during the corresponding months for 1904 and 1905."

Referring to mechanical filters, Mr. Geo. W. Fuller, already quoted, is reported to have said (Senate Paper on the "Purification of the Washington Water Supply," page 203): "If the merits of filters of this type were to be judged from the general knowledge as to their efficiency as now obtained in practice in the majority of cases, the indications are that it would not receive a rating of the highest grade. This seems to be due in part to a lack of the necessary skilled supervision at small plants and in part to a desire to avoid the expense of applying a sufficient quantity of coagulant." In the same report, page 101, Lieut.-Col. Charles Smart says: "The rapidity of the filtration and the frequent disturbance of the sand precluded the idea of a satisfactory removal of bacteria." Again, in the same report, page 133, we find:

TABLE IV.—SHOWING THE AVERAGE NUMBER OF DEATHS FROM TYPHOID FEVER PER ANNUM AFTER FILTRATION TO 10,000 POPULATION.

MECHANICAL FILTERS.

NAME OF TOWN.	AVERAGE NUMBER OF DEATHS FROM TYPHOID FEVER PER ANNUM BEFORE FILTRATION.	AVERAGE NUMBER OF DEATHS FROM TYPHOID FEVER AFTER FILTRATION.	PER CENT. INCREASE.	NUMBER OF YEARS UPON WHICH STATISTICS ARE BASED BEFORE AND AFTER FILTRATION.
Newcastle, Pa.	1.3	2.8	115	1
Lexington, Ky.	1.8	6.4	256	4

Mr. Ledoux says: "It is entirely probable that the water supply has absolutely nothing to do with the increase of typhoid fever during the periods mentioned." This is a supposition which any one can make, but the evidence afforded by Scranton, Ithaca, Butler, and Plymouth, seems to prove that water is the principal vehicle of typhoid fever, and it is a little late in the day to attempt to throw

the blame of typhoid on anything but the water supply. The so-called "residual" causes of typhoid, such as milk, vegetables, fruit, and well-water, may account for some cases, but these causes have always existed and will always exist. If anything, they have been improved of late. It seems, therefore, perfectly fair to judge of the success of a filtration system by its effect upon the morbidity and mortality of the inhabitants.

Mr. Ledoux suggests "that the application of the principles of mechanical filtration to the Lancaster filter plant was an after-thought resulting from a failure." Our critic is mistaken; it was part of the original design, as explained in the paper, to meet the exceptional need of the water in time of flood, and at no other time.

Mr. Ledoux cites his experience concerning the indication for cleaning mechanical filters, and he says that he knows of no other than the rising pressure or the loss of head, which may vary from 10 feet to 50 feet, and he does not agree with the author, whom he quotes as saying that "the filter attendant knows that the filter needs washing (only) by reason of the dirt coming through." The author did not say "only," and his information was gathered in part from the following references:

Report of Mr. Geo. W. Fuller on the investigations of Louisville, 1898, page 97: "*Decision to Wash the Filter.*—This decision was one which required considerable judgment. During the whole test no case was recorded where the Warren filter was washed on account of the entire available head having been used, and the rate falling below the desired quantity. In fact, less than 60 per cent. of the available head obtained with the weir (4.17 feet) was ordinarily utilized. In general, it may be stated that the only immediate guide to the decision to wash the filter at any particular time *was the appearance* of the effluent." Page 101: "Unsatisfactory appearance of the effluent and a utilization of the total available head were the immediate guides to washing." (Jewell filter.) Page 103: "Either the unsatisfactory appearance of the effluent or the decrease in the rate of filtration on account of resistance of the filter were used as immediate guides for the determination ol the time of washing." (Western gravity filter.) The author also refers to the report of the Sewerage and Water Board, New Orleans, 1903, page 137: "*Decision to Wash the Filters.*—It was necessary, as a rule, to operate the filter until the loss of head reached the available limit—10.7 feet—provided the appearance of the effluent was satisfactory." (This refers to filters Nos. 3 and 4 of the Experimental Station.)

Paper No. 1027.

DENATURED ALCOHOL: ITS MANUFACTURE AND SOME OF ITS USES.

HENRY LEFFMANN.

Read September 15, 1906.

The term "alcohol" is of Arabic origin, and in its primitive meaning has no reference to the inflammable principle of fermented beverages. Any substance in a state of fine powder might be intended. Natural antimonous sulfid, used as a cosmetic in the East, is one of the substances originally termed alcohol. By a transition of meaning, due to confusion of ideas, the word has come to its modern meaning. It is not necessary to take up time with a summary of the history of the discovery of alcohol and its recognition as a definite chemical compound. Berthelot, the eminent French chemist, has published an essay which gives all the important data. Aristotle knew that wine will emit an inflammable vapor. Processes of distillation were well known to the Greek alchemists, who were especially active during the early Christian centuries, but they did not isolate alcohol. Definite allusion to an inflammable ingredient, with active physiologic properties, obtainable from fermented beverages—especially wine—is found in a work written about 1300 A. D. and ascribed to Arnold of Villa Nova. He called this product *eau-de-vie* (water of life), and extolled it as a panacea.

In modern chemistry the word alcohol has become a generic term, that is, the name of a type of organic bodies numerously represented. According to this system of classification, the substances commonly called glycerin, carbolic acid, and pyrogallic acid are alcohols, and the common sugars are alcoholic in type. In common usage, however, alcohol means but one substance, the product of the action of yeast on ordinary sugars, this product being known to the chemist as ethyl alcohol, C_2H_5HO.

As sugars are found abundantly in the vegetable kingdom, and as starch, which is still more abundant, can be easily converted into fermentable sugars under natural conditions, the production of alcohol is very easy. The reactions, indeed, belong to the class formerly termed "spontaneous," because they occur without the intervention

of human agency. It is now known that yeast is a living organism—a fungus—and that many species exist. Most of these produce the alcohol fermentation, but a few have a different action, and the accessory properties and flavors of fermented beverages are due in part to the less abundant species. As the common yeasts are almost constantly in the air, any vegetable juice containing a fermentable sugar will, on exposure to air at a suitable temperature, pass into fermentation promptly, and will continue until the sugar is exhausted or the amount of alcohol interferes with the development of the yeast. During this process the yeast multiplies by simple methods, especially by budding. Of late years, much attention has been given to the cultivation of pure yeasts. Following the lead of Hansen, of Copenhagen, manufacturers of fermented beverages select the species of yeasts best adapted to the article to be produced. This is done by brewers of malt liquors (beer, ale, porter), who often devote great care under expert supervision in establishing proper yeast supply. In all alcoholic fermentation, a coincident evolution of carbon dioxid occurs, hence the fermenting liquid effervesces.

The production of alcohol for commercial purposes other than as ingredient of beverages does not require such care. It is carried out by the indirect fermentation of starch, that is, the starch is first converted into a form of sugar, which is fermented. In this country maize (Indian corn) is much used; on the continent of Europe, potatoes are largely used. The fermented liquor is subjected to distillation, by which the alcohol, some of the water, and any volatile by-products are obtained in mixture. This crude spirit, often termed "high wines," is submitted to redistillation, by which most of the by-products are removed. The resulting liquid contains about 95 per cent. of alcohol, and 5 per cent. of water. It is almost odorless, and has a pungent taste without appreciable flavor. It is known as "deodorized alcohol" or "Cologne spirit." It is used for cosmetic and medicinal purposes, and largely for making imitation liquors.

To obtain pure alcohol is difficult and expensive. The strongest form of commercial alcohol is that above noted, 95 per cent. In the ordinary commercial rating, the strength is expressed in terms of an arbitrary standard termed "proof spirit." This contains about 50 per cent. of pure alcohol, and a gallon of this constitutes the "proof gallon" which is basis for taxation in this country. All other strengths are expressed by comparison with this, which is taken as 100. Thus, 95 per cent. alcohol contains about twice as much of the pure sub-

stance as proof spirit, hence is termed 190 proof. The tax is $1.10 per proof gallon, hence a little over $2.00 for the commercial 95 per cent., which is at least six times the cost, so that it is readily seen what a burden this taxation is. Most civilized countries collect considerable revenue by taxation of alcohol.

Alcohol has been used as a fuel for a long time. It has several advantages. It burns with no appreciable smoke, is clean in handling, can be easily extinguished by water, and gives out no odor in burning. Prior to the Civil War, no tax was imposed in this country, and it was largely used for fuel and light. In the chemical laboratory, lamps for high and low temperatures were employed. Alcohol has an advantage over gas in that the latter is more liable to contain impurities, *e. g.*, sulfur and ammonium compounds, and even volatile compounds of iron (iron carbonyl, FeC_4O_4), which may cause serious errors in the more delicate operations of analysis. The alcohol flame is almost non-luminous, but by admixture with turpentine a clean and convenient illuminant can be obtained. This is, however, owing to the volatility of both constituents, dangerously explosive. Prior to the Civil War, it was much used for household lamps under the trade names "camphene" and "burning fluid," and accidents from it were frequently reported.

The burden that the tax places on all industries in which alcohol is used has been felt in every manufacturing community, and many efforts have been made to escape it. To raise revenue by heavy taxation of luxuries has always been a favorite method of governments, which probably consider that the incidence of such taxation is less onerous than any other form. It is obvious that a release from taxation for alcohol applied to special purposes will be attended with great danger of fraud, since it is easy to prepare from ordinary alcohol beverages which will be widely used, especially by the lower classes, for intoxicating purposes. Legislators have, therefore, sought to prepare the alcohol in such a way as to render it unfit for any but technic uses. The favorite plan is that commonly termed "denaturing," that is, to add a small amount of some substance which is so offensive to taste and smell as to make the prepared spirit nauseous. It is obvious that this substance must be cheap, difficult of removal, not seriously dangerous to health in the proportion used, and not likely to interfere with any of the technic uses. The number of substances complying with all these requirements is not large. For a long while, notably in England, an addition of the crude spirit obtained

in the distillation of wood was used, and this so-called "methylated spirit" figures prominently in the writings of English analysts.

A long agitation for the official recognition of tax-free alcohol in the United States has just been ended by the approval of a bill which will take effect very soon. It does not provide the details of the denaturing, but merely covers the general features of administration and leaves to one of the government departments the formulating of the methods and substances to be used. Up to this time no official decisions have been published. The methods that have been elsewhere most approved are the above-mentioned use of crude wood-spirit and the addition of pyridin. Pyridin is a complex nitrogen compound existing in coal-tar and in the tar from the destructive distillation of bones. It is offensive and not easily decomposed or removed from the alcohol.

The important question from an engineering point of view is that of cost. The most recent and probably the most trustworthy data on this point, applicable to this country, are to be found in the report of the Committee on Ways and Means, submitted to the last session of Congress (59th Cong., 1st sess., 2888).

The market-price of strong alcohol is from 25 to 40 cents per gallon exclusive of tax. The figures for its manufacture on a very large scale were taken from the books of a Peoria distillery, averaging ten years of operation. The average price of corn during those years was 42.36 cents per bushel, and the average yield was 4.76 proof gallons from a bushel. Inprovements in distilling increase this yield now to 5 proof gallons per bushel. The manufacturing cost averaged 1.89 cents per proof gallon. For 90 per cent. alcohol, which is the strength used in motors, the cost will be 3.64 cents per wine gallon. Applying the improved methods of distillation, the committee estimates that with corn at the above average price per bushel, and with no material increase in operating, the total cost will be about 18.4 cents per wine gallon. Crude wood-alcohol costs 40 cents per gallon to manufacture. If 10 per cent. of this were used in denaturing, the cost of such denatured alcohol would be 20.5 cents per wine gallon. At this price it would compete with gasolin, and in the Northwest, where gasolin is higher and corn cheaper, the competition would seem to be still more active. It must also be borne in mind that the supply of gasolin is limited, while that of alcohol is unlimited.

Corn is by no means the only source of alcohol. A very abundant source is the waste molasses—especially beet-sugar molasses—the

alcohol from which is of inferior value for liquors and medicines, but of equal value with the best alcohol for burning. It is reported by United States officials, that in Cuba this molasses alcohol is made at a cost of ten cents per gallon. As the by-product of beet-sugar goes largely to waste, on account of the inferior quality of the alcohol, the utilization of this will be a powerful factor in the development of the beet-sugar industry.

The committee states that experiments show that one gallon of 90 per cent. alcohol will produce at least 10 per cent. more power than a gallon of gasolin. As alcohol can be burned in a lamp with a wick without producing soot, it is possible to use a Welsbach mantle directly, which cannot be done with petroleum products, and a gain in illuminating power can be obtained. Experiments in the testing laboratories in New York City gave for one gallon of alcohol, used with a Welsbach mantle, 1471 c.p. hours, against a good quality coal oil = 783 c.p. hours. The alcohol lamp gave 25 c.p.; the coal-oil lamp gave 9 c.p.

The following are some practical data that have appeared from trustworthy sources during the past few years.

The German Society of Manufacturers of Spirits reports that experiments showed that:

1 kilo of 90 per cent. alcohol gave	5,500 calories.
1 kilo of petroleum spirit (gasolin) gave	10,300 calories.
1 kilo of kerosene gave	10,300 calories.

In the best steam-engines only 15 per cent. of the heat is converted into useful work, but in modern spirit-engines 33 per cent. is so obtained, compared with 21 per cent. with gasolin and 18 to 19 per cent. with kerosene.

The following data are from the "Engineering and Mining Journal," 1903, 75 (25), 938:

Methylated spirit	10,620 B. T. U. per pound.
Methylated spirit and 50 per cent. kerosene	14,200 B. T. U. per pound.
Crude American petroleum	19,630 B. T. U. per pound.
Refined American petroleum	19,880 B. T. U. per pound.

It is stated that with the Welsbach lamp properly adapted, 125 grams of alcohol, costing 3 pfennings, will give 50 Hefner candles, and 100 grams of petroleum, costing 2 pfennings, will give 24 Hefner candles.

Behrend (abst. "J. S. C. I.," August 15, 1902, 1020) gives the cost of B. H. P. hour at 3 cents with alcohol.

In Hanover fire engines have been adapted to the use of alcohol as fuel.

DISCUSSION.

Mr. Foster.—I would like to ask if any attention has been given to the cost of production of alcohol in places remote from the general trade centers. For instance what would it cost in smaller plants than those at Peoria? It is to be presumed that on the plains of Montana or elsewhere, the cost of production of alcohol would scarcely be so low. But on account of its general handiness and freedom from fire risk, I quite agree that the development of power from alcohol engines is a probability, but I doubt if the cost can be given at present. I think there has been a statement made recently by one of our Consuls who went to Germany to look into the matter of the use of alcohol, and found that it was not being used to any such great extent as has been stated in the newspapers.

I would like to ask in regard to the effect of using wood alcohol in producing blindness, that is what length of time it takes to produce such effects, where the vapor is simply inhaled?

Another thing is, how far is the Government encouraging the manufacture of denatured alcohol, opposed as it might be to its loss of revenue?

P. A. Maignen.—With regard to the denaturization of alcohol there are very few substances which can be mixed with it and which cannot afterward be removed by chemical action or charcoal.

If it were possible to put in the alcohol a color that could not be taken out it would be a very good way of preventing fraud and error, but nearly all coloring matters can be removed by charcoal, and they can certainly be removed by distillation also.

A combination, therefore, of color and some nauseous substances should be used. Substances added to alcohol to give it a bad taste are generally mixed with the spirit after distillation. If they were added before distillation they would rise up with the vapors which become alcohol by condensation, and the union would be more intimate and more difficult to undo.

I understand that alcohol is made from corn stalk. Is it green or dry? Is there enough fermentable substances in the dry stalk to make alcohol, as is the case with dry raisins, from which wine can be made, or must it be distilled when yet green, and is it macerated with water to excite fermentation? In other words, how is alcohol extracted from corn stalk?

Henry Leffman.—The green corn stalk can be crushed and the juice fermented with yeast.

President McBride.—A comparison of alcohol and gasoline for use in internal combustion engines illustrates nicely the increased efficiency obtained from increased compression in engines of this type. While alcohol is capable of giving but about two-thirds of the heat per unit volume of gasoline, yet it can stand much higher compression and therefore be used so much more efficiently that, volume for volume, gasoline and alcohol properly used will give about the same power. Either will develop a horse power from a pint or a little over. This capacity for higher compression enables any given engine to produce a greater total amount of power with alcohol than with gasoline.

As the use of alcohol instead of gasoline means less heat in the cylinder, it looks as though air-cooled engines would work well with alcohol; and that we might expect to see the air-cooled engine with alcohol in much larger sizes than we now have with gasoline.

Referring to the figures of cost of gasoline given in the paper there is a great difference in the cost of gasoline under different circumstances. Gasoline is sold by the refiner in tank carload lots at about nine cents per gallon. Dealers in automobile supplies charge twenty cents and over. Do the figures given as the cost of alcohol correspond to the nine or the twenty cent figure for gasoline?

F. N. MORTON.—Perhaps some of the testimony given in Washington will be of interest. The representative of the Otto Engine Company in his testimony declared that using a gasoline engine with alcohol gave a little less power per gallon than it did when using gasoline, and they then took the same engine and increased the compression, and the engine produced the same power as it did with gasoline. They had a good deal of trouble in starting engines with alcohol in Germany, but managed by first starting the engine on gasoline, and then changing over to alcohol. It was brought out that in this country an engine could be built which would successfully start on alcohol.

PAPER NO. 1028.

THE NEW ENGINEERING BUILDING AND EQUIPMENT OF THE UNIVERSITY OF PENNSYLVANIA.

THE stated meeting of the Club on November 3d was held in the new engineering building of the University of Pennsylvania by invitation of Professor Henry W. Spangler and Professor Edgar Marburg, Members of the Club, and Professors of Dynamical Engineering and Civil Engineering, respectively, in the University.

After the meeting, at which addresses were made by President McBride, Professor Spangler, and Professor Marburg, the Club was conducted through the building and inspected its many interesting features.

The size of the building, the excellence and completeness of its equipment, largely of new and special design, and the liberal provision for instruction by modern laboratory methods, make the plant as a whole a notable addition to the technical educational facilities of the country, and its dedication on October 19th with impressive ceremonies attended by distinguished engineers from other States and abroad was an important event to the engineering profession.

The building is the largest of the University group of seventy buildings, having a frontage of 300 feet and depth of 210 feet at one end, and 160 feet at the other. The general architectural treatment is in the English Georgian style, the exterior being of dark brick with limestone trimmings. There are three stories with a basement covering about a third of the entire building, the total floor area being about 128,000 square feet. The cost, including equipment, is nearly a million dollars, and the construction is fireproof throughout.

The building is lit by electricity, current being supplied during times of small demand directly from the light and heat station, and when the demand is large, from the local plant in the center of the basement. This plant consists of two 75 H. P. Westinghouse standard engines and one 25 H. P. directly connected to general electric generators.

Steam for the engines is supplied from the central station, and after being used by the engines is sent into the heating system of the building.

The lighting of the halls and library is by 50 candle-power meridian

lamps. The class-rooms are lit by clusters near the ceiling. The drawing-rooms and laboratories are lit generally by 5 ampere enclosed arc lamps, with opaque bottom shade and concentric diffuser, placed about 15 feet apart. The distribution of the light is very uniform.

Each room in the building is heated by steam-coils supplied with low-pressure steam. In the small rooms having but one steam-coil, the coil is so subdivided that all, or a portion of it, can be put on at one time.

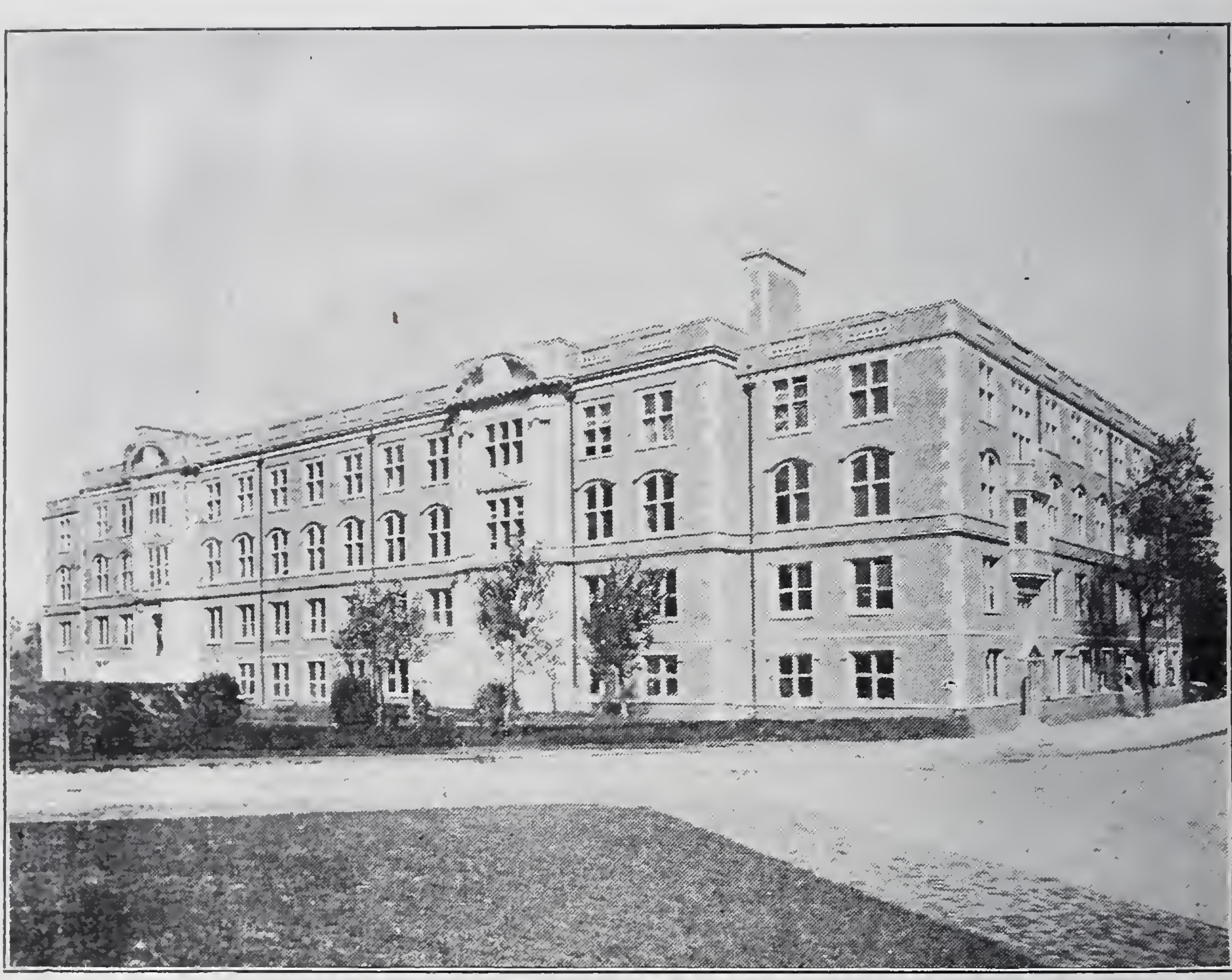
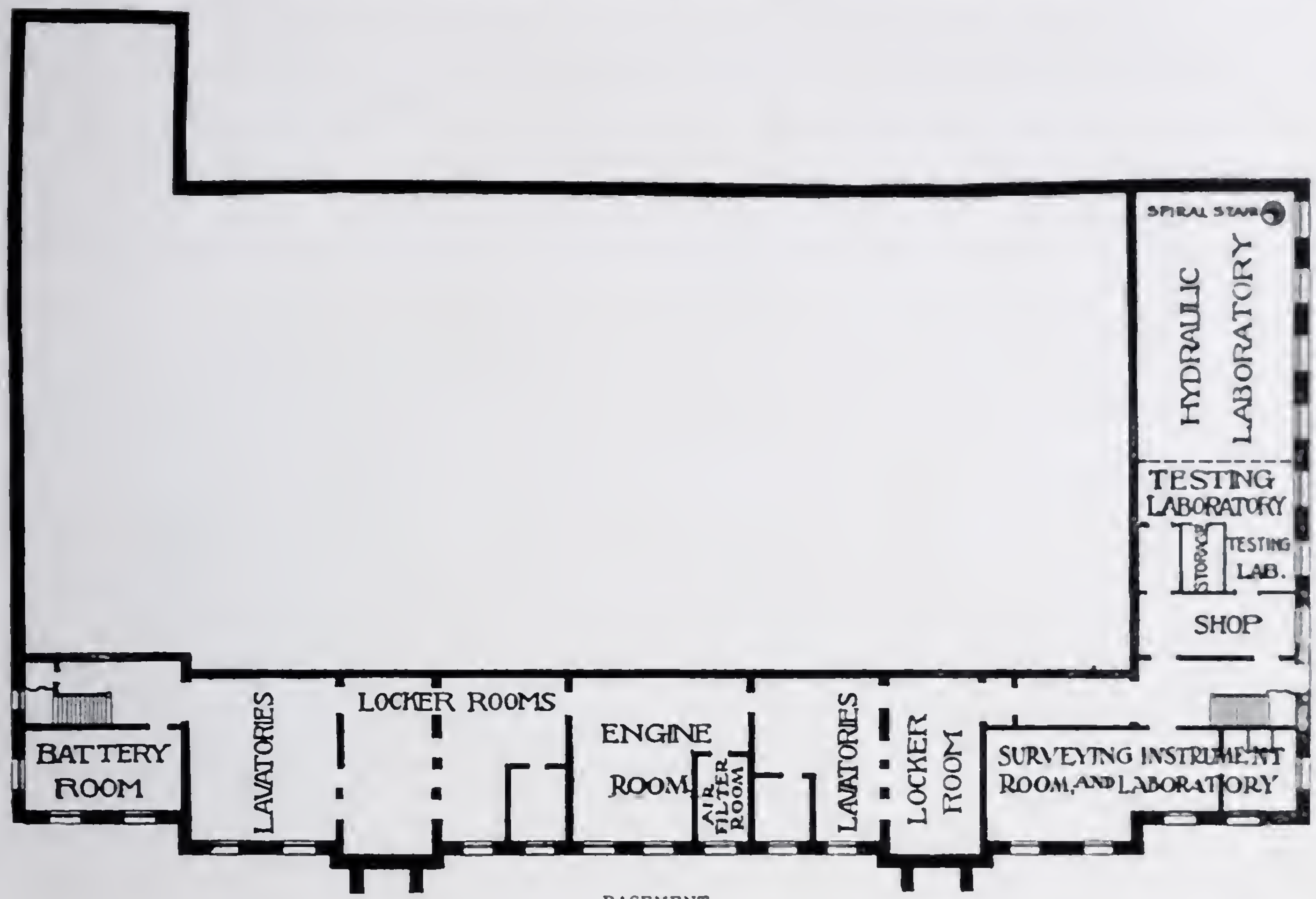


Fig. 1.—Front Elevation.

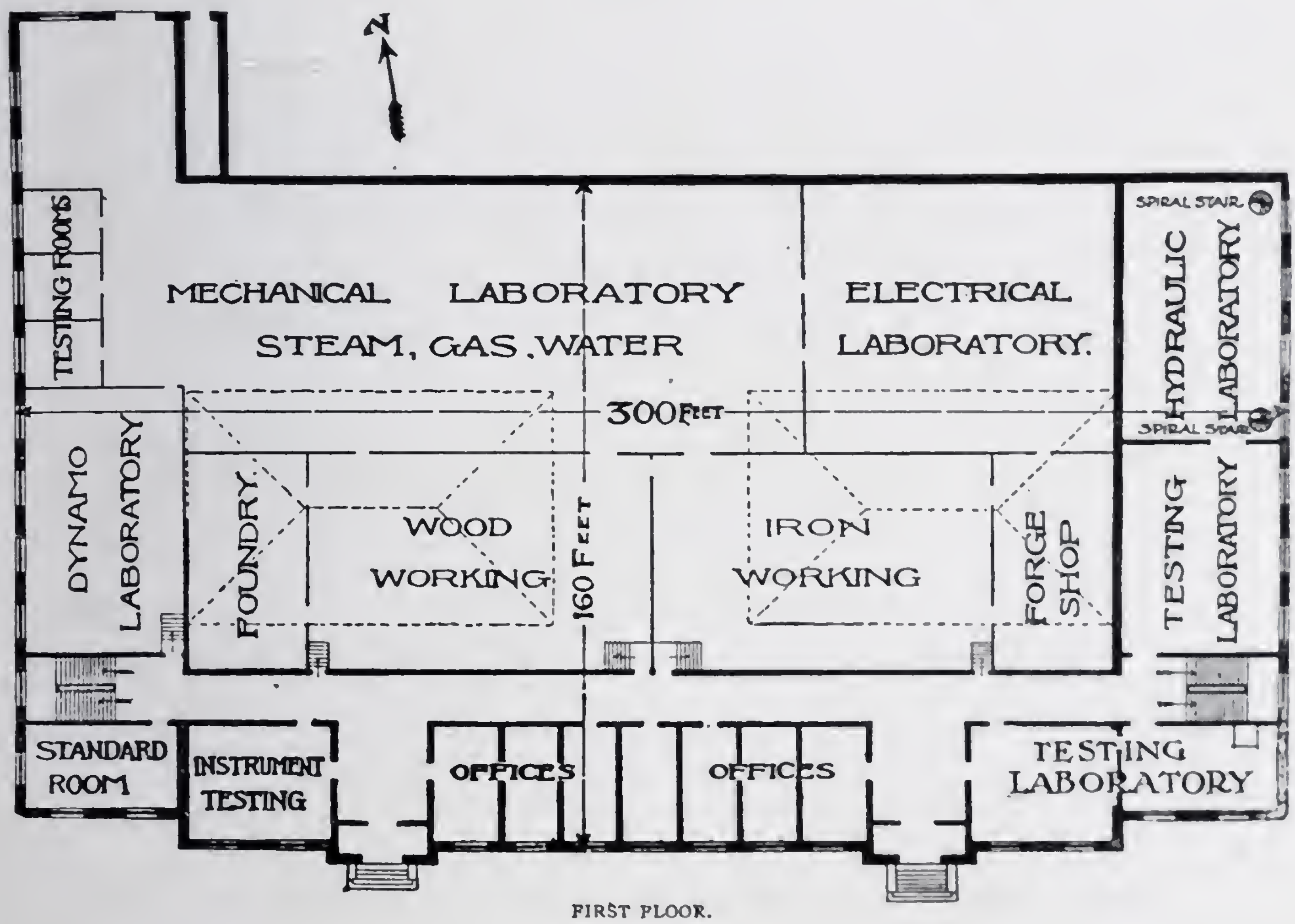
The distributing system is in the attic and takes either the exhaust steam from the engines or live steam through a reducing valve from a steam main.

All the rooms in the building are ventilated by fans located either in the attic or in the basement. The system is divided into sections, each with separate fan and tempering coils, so that only that portion of the building in use has fresh air pumped into it. These fans are under distant control, the starting-box being located at a convenient



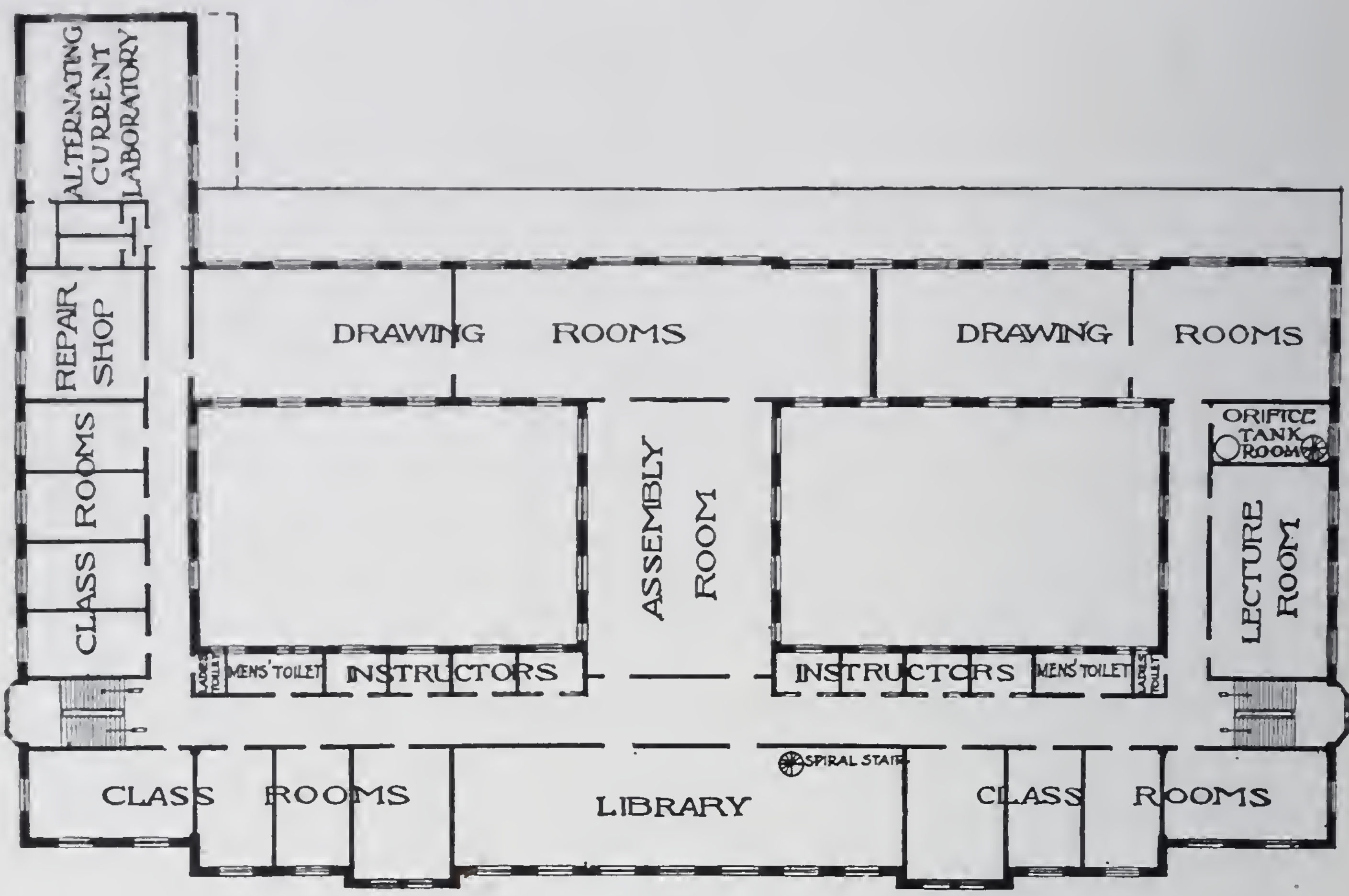
BASEMENT.

Fig. 2.



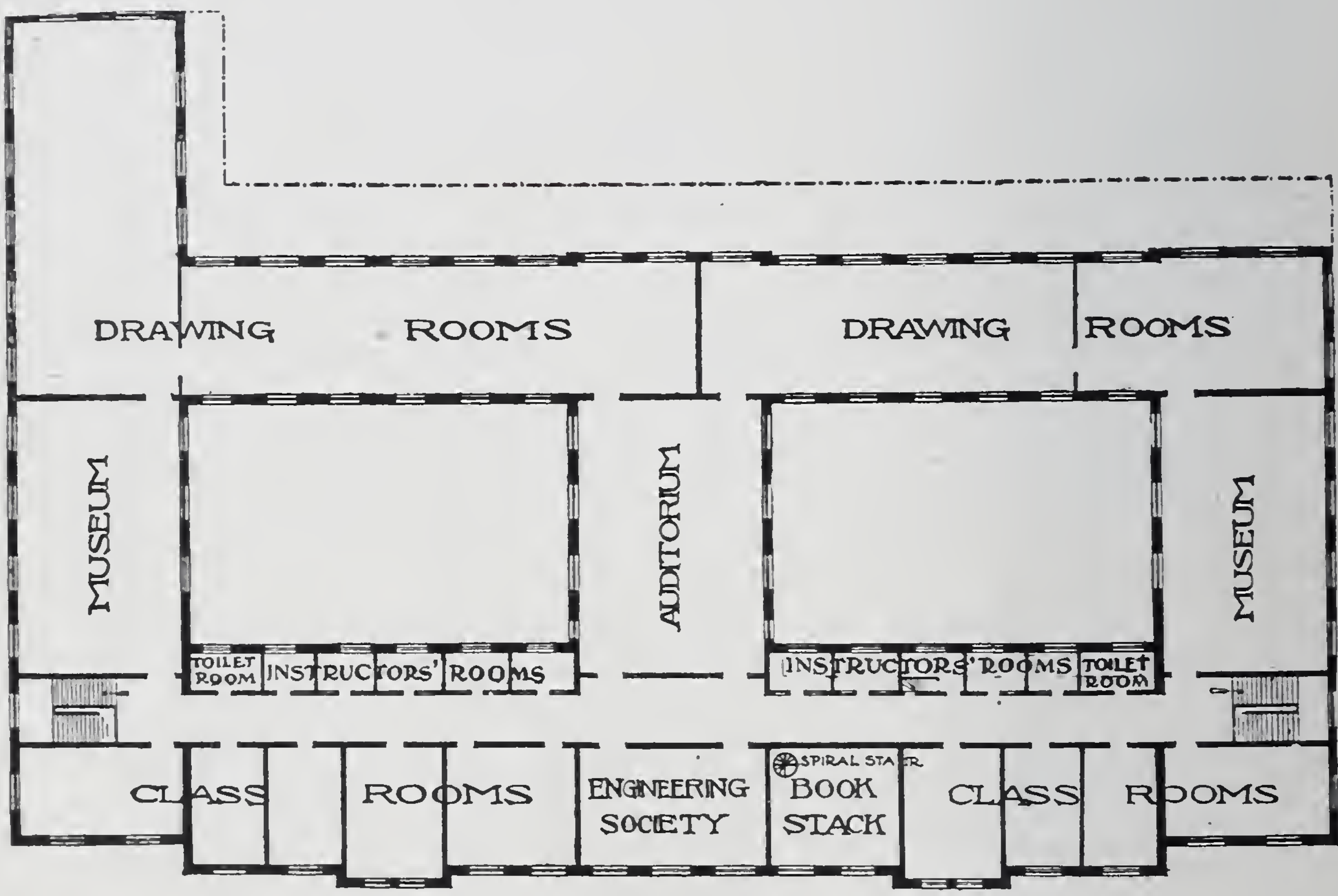
FIRST FLOOR.

Fig. 3.



SECOND FLOOR.

Fig. 4.



THIRD FLOOR.

Fig. 5.

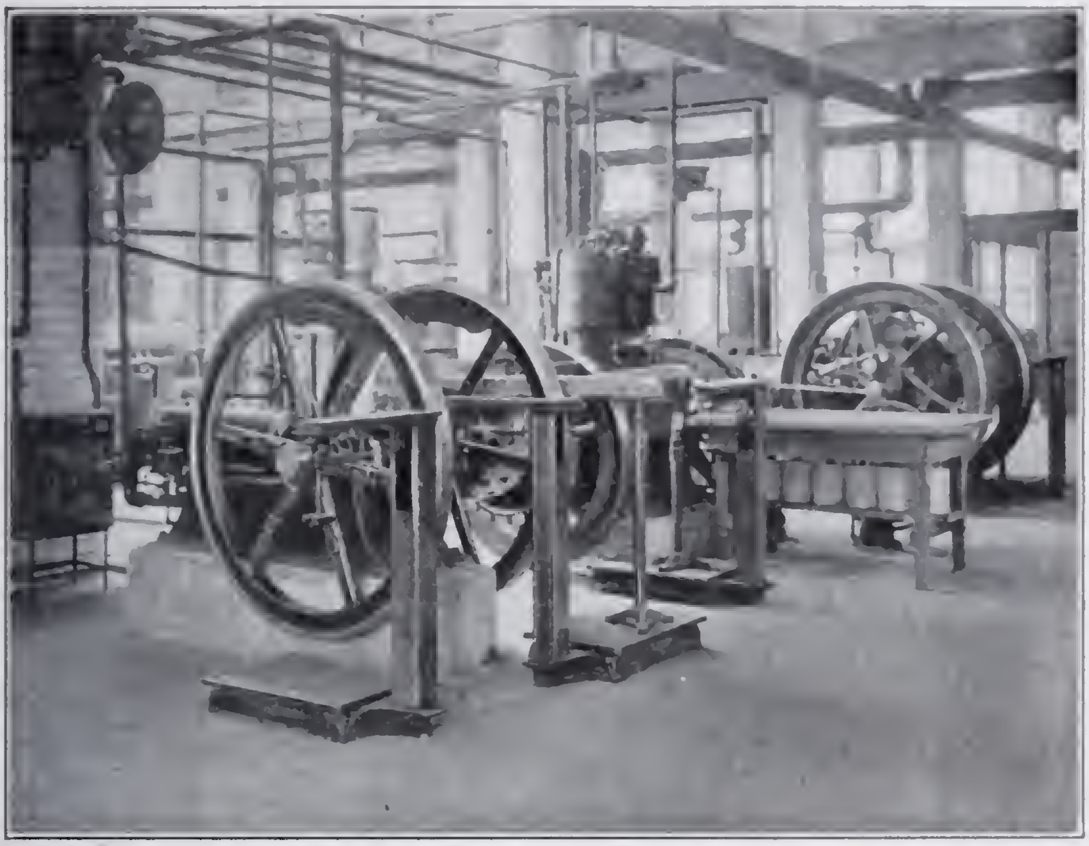


FIG. 6.—A CORNER IN THE MECHANICAL LABORATORY. THE GAS-ENGINES.

FIG. 7.—THE STEAM LABORATORY.

point so that the instructor in charge of any department of the work can control the ventilation. The speed of the fans is regulated by rheostats at the fans themselves. Air is forced into all the living rooms and exhausted from the toilets.

Mechanical and Electrical Engineering.

Mechanical Laboratory.

The mechanical laboratory is located on the first floor and occupies a total floor space of about 14,000 square feet. It is in the form of

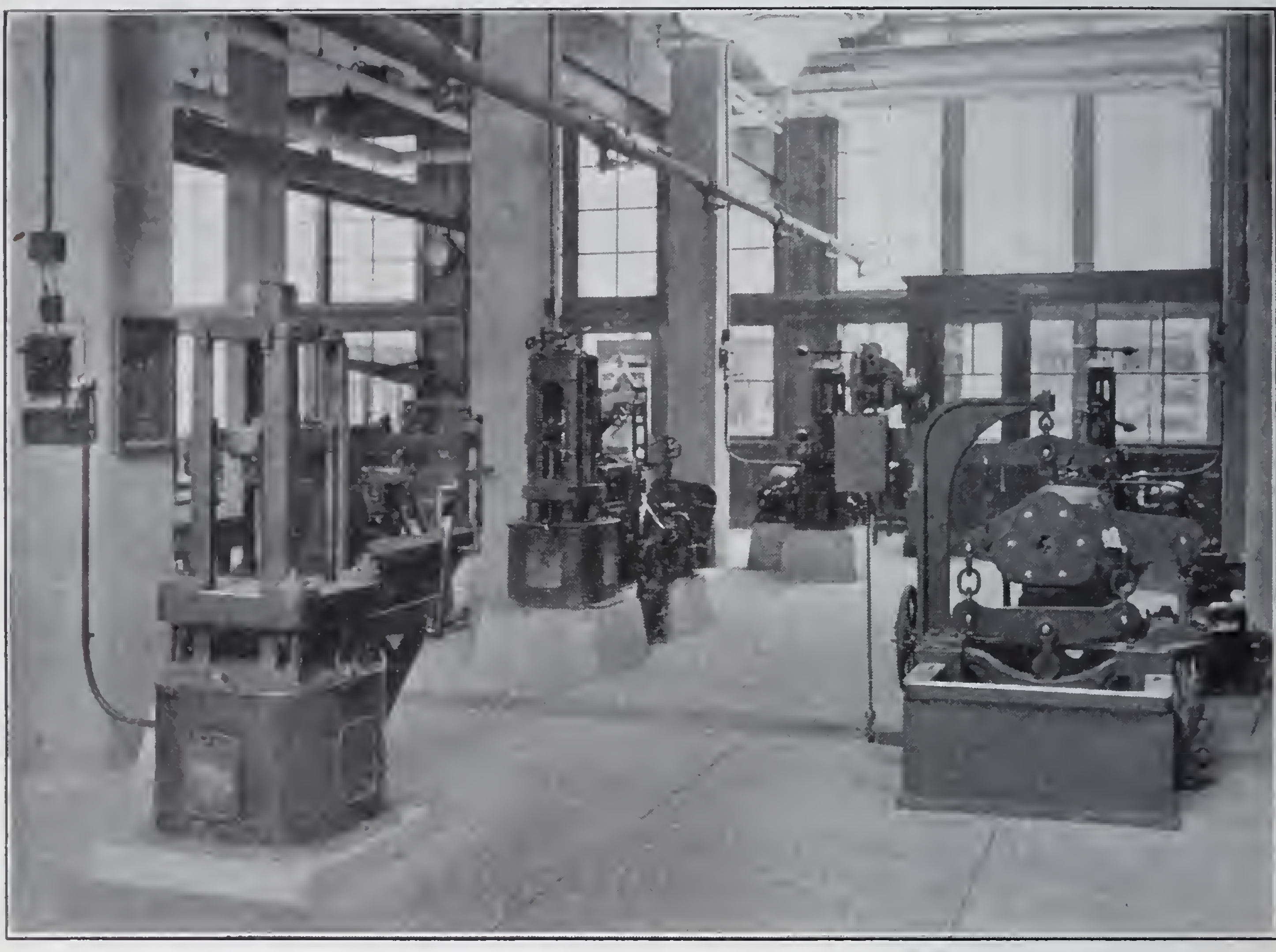


Fig. 8.—Material-testing Laboratory.

the letter "L," the main portion of the laboratory being 183 feet long by 64 feet wide and the smaller portion 40 feet long by 38 feet wide.

The apparatus is placed in groups, those relating to allied subjects being located together. The gas-engine plant (Fig. 1) consists of four gas-engines of various sizes and makes, properly equipped for making all classes of tests on them. A 100 H. P. Roberts high-pressure boiler is provided for making boiler tests and for supplying highly superheated steam for testing purposes.

The steam laboratory proper (Fig. 2) is supplied with steam from the central station. It contains a number of engines from a vertical compound of about 35 H. P. to a small DeLaval steam turbine, and has, among other steam-driven appliances, a two-stage Ingersoll air compressor, a Harrisburg engine exhausting into a Wheeler condenser, a Snow pump with jet condenser, a Porter-Allen engine, an Ames engine, a Hamilton Corliss, and a Fairbanks engine, together with all the small appliances required for testing them. In that portion of the laboratory devoted to material testing (Fig. 3) there are four machines from 30 to 60,000 pounds for tension and compression work, two machines for torsion work, each of which is sep-

Fig. 9.—Electrical-instrument Laboratory.

arately motor driven. The dynamometers for measuring power transmitted are installed in another portion of the laboratory. For hydraulic work numerous tanks, meters, pumps, and water-wheels have been provided.

Each of the machines in this laboratory has been installed for use in making certain classes of experiments, and the appliances supplied with each machine are such that the entire work of the laboratory may be carried on at one time. The laboratory is equipped with a large number of indicators, gauges, revolution counters, and the innumerable small appliances required for the carrying on of work of this type.

In addition to the laboratory proper, a room intended for the testing of instruments and for making tests of coal and gas, and for the similar work required of a mechanical engineer, has been located on the first floor.

Three small rooms, in addition, are provided, in one of which a refrigerating machine is installed; in the second, the apparatus for making tests on blowers and heating appliances, and in the third room, apparatus for the testing of radiation through walls of various types.

Electrical Laboratory.

Four electrical laboratories are provided, three on the first floor and one on the second.

FIG. 10.—DIRECT-CURRENT DYNAMO LABORATORY.

The beginners' laboratory (Fig. 4), located on the first floor, is intended for measurement of current, resistance, inductance, capacity, etc., the calibration of voltmeters, ammeters, wattmeters, etc., and a floor space of 4500 square feet is divided into four separate testing rooms. A concrete table and a galvanometer pedestal are provided for each student, there being accommodations for forty-two men divided into four sections. Each of the four sections is provided with its own switchboard and its own storage battery insulation, enabling the entire number of men to be working at the same time.

The distributing switchboards have been designed for the work and it is possible to get any combination of direct or alternating current for testing purposes. The apparatus supplied for these laboratories is believed to be without its equal in any technical laboratory in this country.

The testing laboratory for direct current (Fig. 5) has a floor space of about 2000 square feet. It is on the ground floor and has all its apparatus mounted on raised foundations to which any dynamo or motor can be attached. Provision is made for handling twelve tests at one time, and the apparatus for each of these is complete. The distributing switchboard here supplies current of 110 volts or at 6, 20, 110, or 150 volts, or any combination. The main power supply is taken from the building plant, 500 amperes being available to 110 volts.

All the dynamos used are motor driven, having field rheostats for regulating purposes. The appliances required for making these tests are supplied in such numbers that it is possible to run this entire laboratory at the same time, doing any of the work for which any of the machines may have been installed.

The alternating current laboratory is located on the second floor. Its total floor space is over 2100 square feet. The wiring in this room is overhead from a switchboard supplied for handling the work here. This board is over 14 feet in length, and all the circuits are protected by circuit breakers. The apparatus installed is such that each testing place is practically a complete isolated plant.

For supplying current, four direct connected generator sets are used, driven by direct current motors, three sets having polyphase generator and the fourth having four single-phase alternating current generators.

To give some idea of the small instrument equipment for each location, there is the necessary equipment of prony brakes, scales, adjusting resistances, switches, thermometers, speed counters, stop watches, and tachometers, and, in addition, there are about 90 instruments, 20 of which are for direct current, the remainder being wattmeters, ammeters, and voltmeters of suitable range for the rapid and accurate carrying on of the work, together with frequency indicators, power factor indicators, and synchronizers.

Two rooms are built especially for student's work in photometry, these having labyrinth entrances and dull black walls. A separate storage battery is provided for handling this work. Each photometer

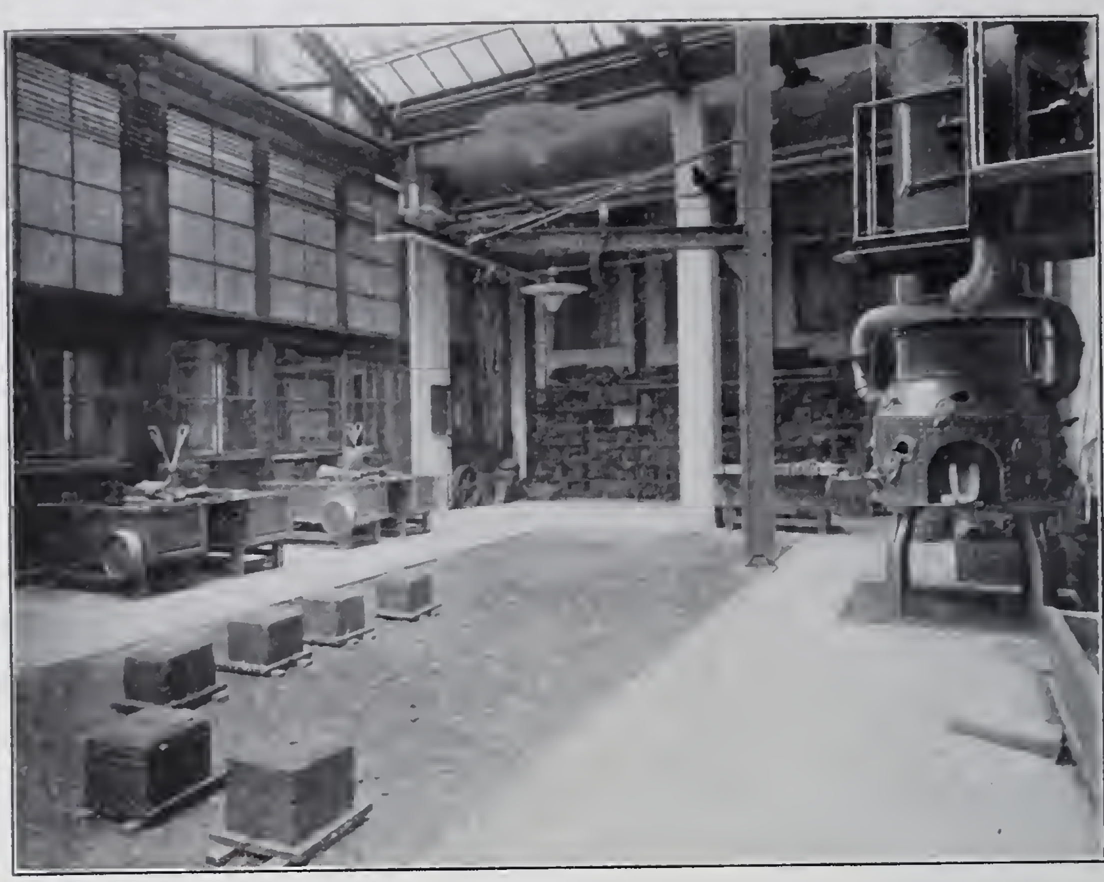


Fig. 11.—Foundry.

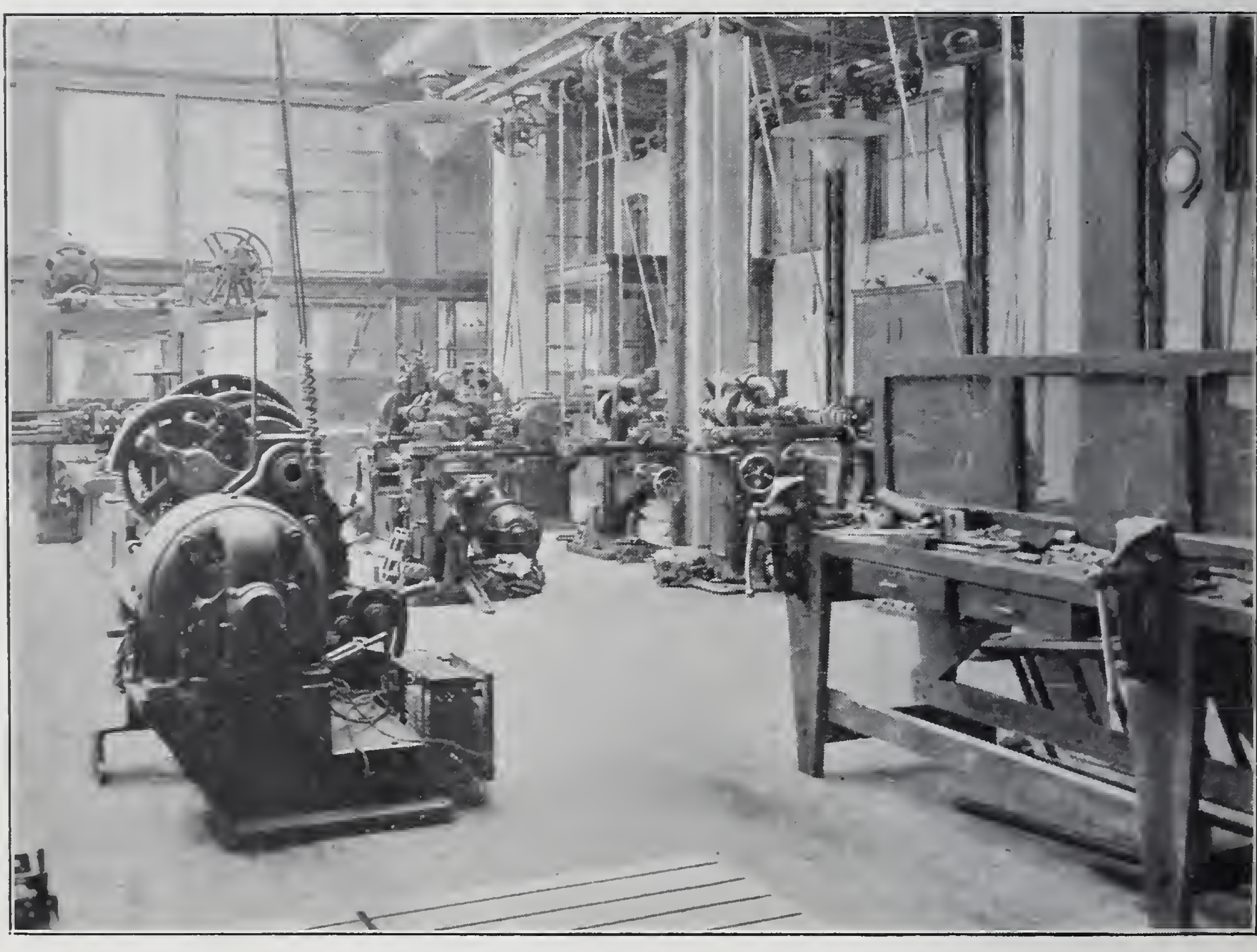


Fig. 12.—Iron-working Shop.

has a three-meter track and universal rotating stand. One is provided with the Lummer-Brodhun screen, and one with the Bunsen screen, and a Flicker photometer is provided for use in measuring lights of dissimilar composition.

A standard room on the first floor with a battery room directly beneath it in the basement has been provided for doing fine electrical standardization work.

Shop.

About 12,000 square feet of space on the ground floor under the

FIG. 13.—FORGE SHOP.

skylights is used for shop work, and includes lumber and iron room, offices for instructors, and a large central tool room. It is divided into wood and pattern shops, iron and machine shops, foundry and forge shop. Each shop is arranged for handling fifteen men at one time, or a total of ninety in a class.

These shops are supplied with a modern equipment of tools, the pattern shop having turning lathes, band saw, jig saw, jointer, surface planer, rip and cross-cut saws, sanding machine, etc. The foundry

(Fig. 6) has 10 large molding troughs, a 22-inch cupola, two brass furnaces, and a large molding floor. The iron shop has 14 lathes, drill presses, vises, etc. The machine shop (Fig. 7) has two drill presses, cutter grinder, universal lathe and planer tool grinder, twist drill grinder, emery wet grinder, 9 moderate-sized lathes, one 30-inch × 12-foot high-speed lathe, three milling machines, two shapers, two planers, one 38-inch × 38-inch × 10-foot, screw machine, and numerous smaller tools. The forge shop (Fig. 8), in addition to its equipment of forges, has a steam hammer, drill press, tool grinder, power punching machine, shears, pipe cutting apparatus, etc.

For shop work throughout the most modern appliances have been furnished so that a student may rapidly learn the quickest and best method of making patterns, moulding and casting them, and finishing them in the machine shop. A repair shop is located on the second floor containing about 900 square feet of floor space, where all broken appliances are repaired and much new apparatus is manufactured. The equipment is complete, for both wood and iron work, and tools are all motor driven.

Drawing Rooms.

The drawing rooms are located on the north side of the second and third floors and cover 11,800 square feet. The largest room is devoted to Freshman work and is 117 feet long by 32 feet wide. This room is divided by a 9-foot high partition (the ceiling being 14 feet high) from the Sophomore drawing room, which is 86 feet long by 37 feet wide. Midway of the partition is an instructor's office, which gives the instructor full command of both rooms, at times when classes are not in session. The Senior and Junior rooms are on the second floor and form practically one room 152 feet long by 32 feet wide, with an instructor's office between. Provision is made for independent work of 101 Freshmen, 93 Sophomores, 75 Juniors, and 46 Seniors.

The lighting of these rooms is excellent. The windows are wide and high, those on the south opening on the west court, which is 55 feet wide. The artificial light, which is needed on winter afternoons, consists of 110-volt enclosed arc lamps with opaque lower globes and concentric diffuser shades, the distribution being such that there is practically no shadow.

A drawing table and stool is assigned to each student in the upper classes for exclusive use during the college year. These tables are 30 × 54, of red oak with pine tops, and contain a drawer for instru-

ments and a closet for boards and T-squares. No such equipment has ever before been provided for doing work of this type.

Class-rooms.

There are thirteen class-rooms in the western end of the building, each intended to handle a small section. The entire available wall space is covered with blackboards so that it is possible to insure daily work from every student. In the basement at the west end is a large lavatory supplied with washing facilities and with shower-

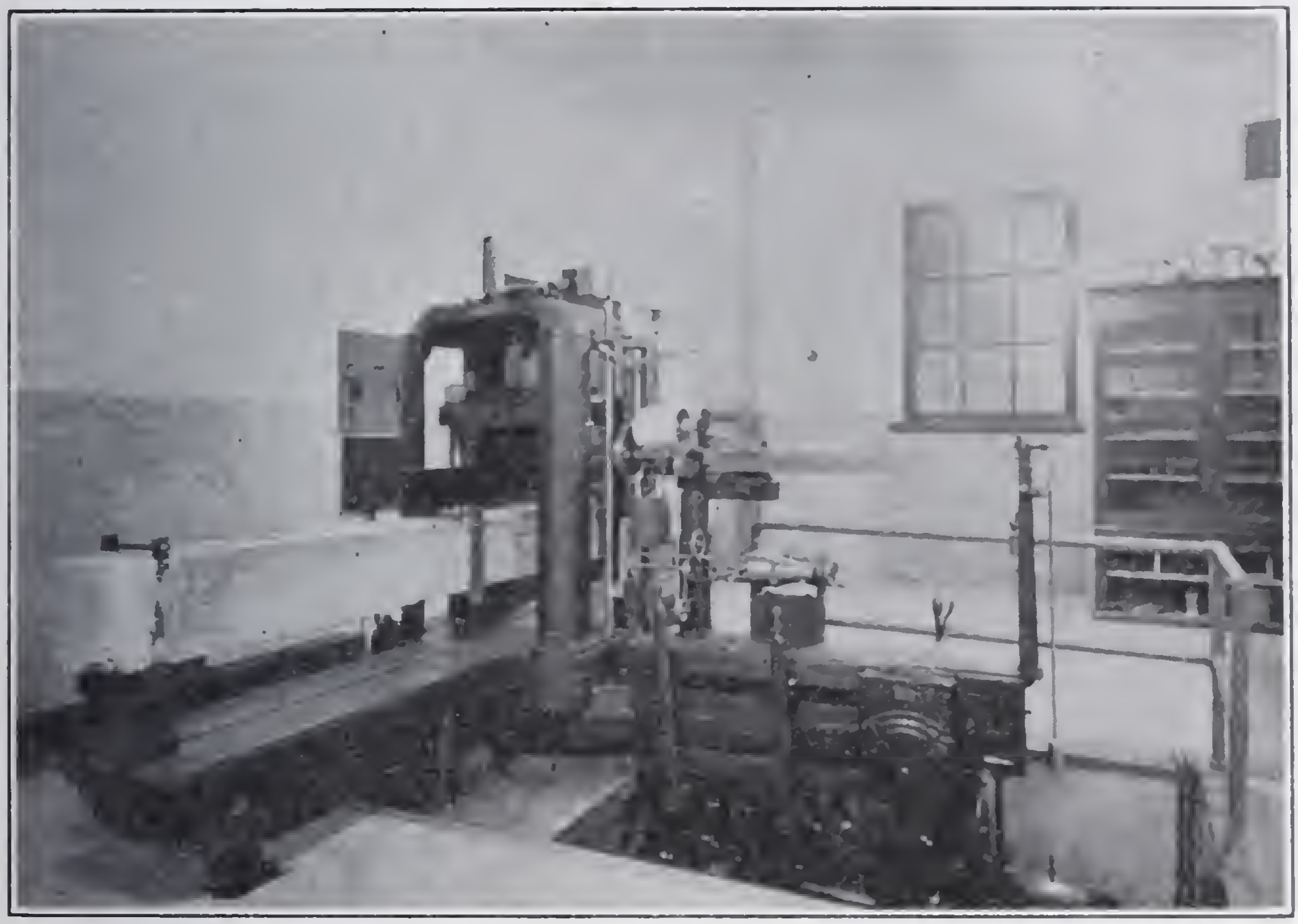


Fig. 14.

baths. Directly adjoining are two locker-rooms, provided with expanded metal lockers of ample size, one being assigned to each student.

In all the work done in the department students are divided into small sections, the instruction being largely individual. In laboratory work especially the work is done absolutely independently, a student being assigned his work and obliged to see that his apparatus is in proper shape and to carry out the experiment directed alone.

Much of the furniture and apparatus installed in the building has

been designed in the department and is especially adapted for the character of work being done. There are no great innovations in the plant, as it is simply an expansion of the work that has been heretofore done in the department, and the experience gained in the old building has resulted in the installing of apparatus which is especially adapted for the work to be carried on, and the installation, as a whole, is complete.

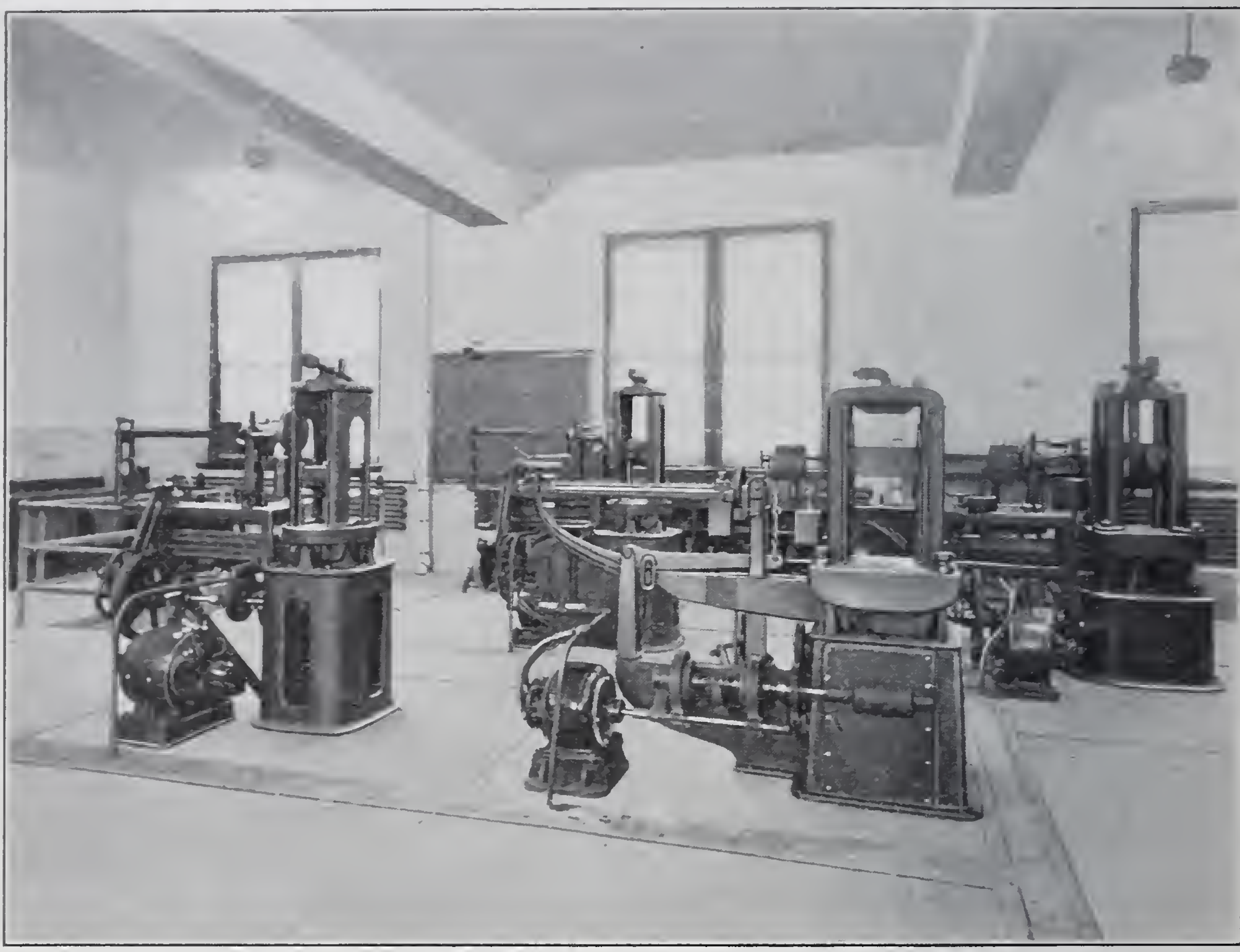


Fig. 15.—Universal Testing Machines of Capacity from 30,000 Pounds to 100,000 Pounds, in Material-testing Laboratory.

Civil Engineering.

Material Testing Laboratory.

The laboratories for testing materials other than cement, covering a floor area of about 3000 square feet, occupy a room on the first floor and two rooms in the basement. The floor of the former is of massive reinforced concrete construction supported on steel beams and designed for a working load of 500 pounds per square foot.

The largest machine in these laboratories—with a capacity of 600,000 pounds—is under contract but not yet installed. It is an Olsen ver-

tical four-screw machine of the universal type, capable of receiving a column 24 feet long, and is provided with beam extensions below the floor level 21 feet long designed for a load of 200,000 pounds on a span of 20 feet.

The equipment consists, in addition, of a 200,000-pound Olsen, three-screw universal machine with beam extensions 13 feet long designed for a load of 120,000 pounds on a 12-foot span (Fig. 9); a 100,000-pound Olsen machine; two 30,000-pound Olsen machines; one 30,000-pound Falkenau-Sinclair machine (all as shown in Fig. 10); one 60,000-inch-pound torsion machine, an autographic pendulum-

Fig. 16.

torsion machine of the Thurston-Riehle type; a 100,000-pound transverse machine; a cold-bend machine, capable of bending a steel bar one square inch in section; and a 15,000-pound wire-testing machine adapted also for receiving compression specimens up to a length of three feet (all as shown in Fig. 12). With the exception of the transverse, the wire-testing, and the pendulum-torsion machines designed for hand operation, all of these machines are driven by independent electric motors.

These laboratories are further equipped with a great variety of special apparatus, including two beam fiber extensometers; a Henning

recorder; a Johnson and Ewing extensometer, the latter reading to $\frac{1}{50000}$ of an inch; an Olsen compressometer reading to 0.0001 inch; two deflectometers; shearing apparatus for iron, steel and timber, besides a large assortment of micrometers, calipers, speed indicators, and tools for the preparation and marking of specimens.

A small room in the basement contains two rattlers for testing paving bricks, which may be operated singly or jointly by an electric motor. A well-equipped machine shop is provided in the basement for the construction and repair of apparatus and the preparation of test specimens for use in the laboratories.

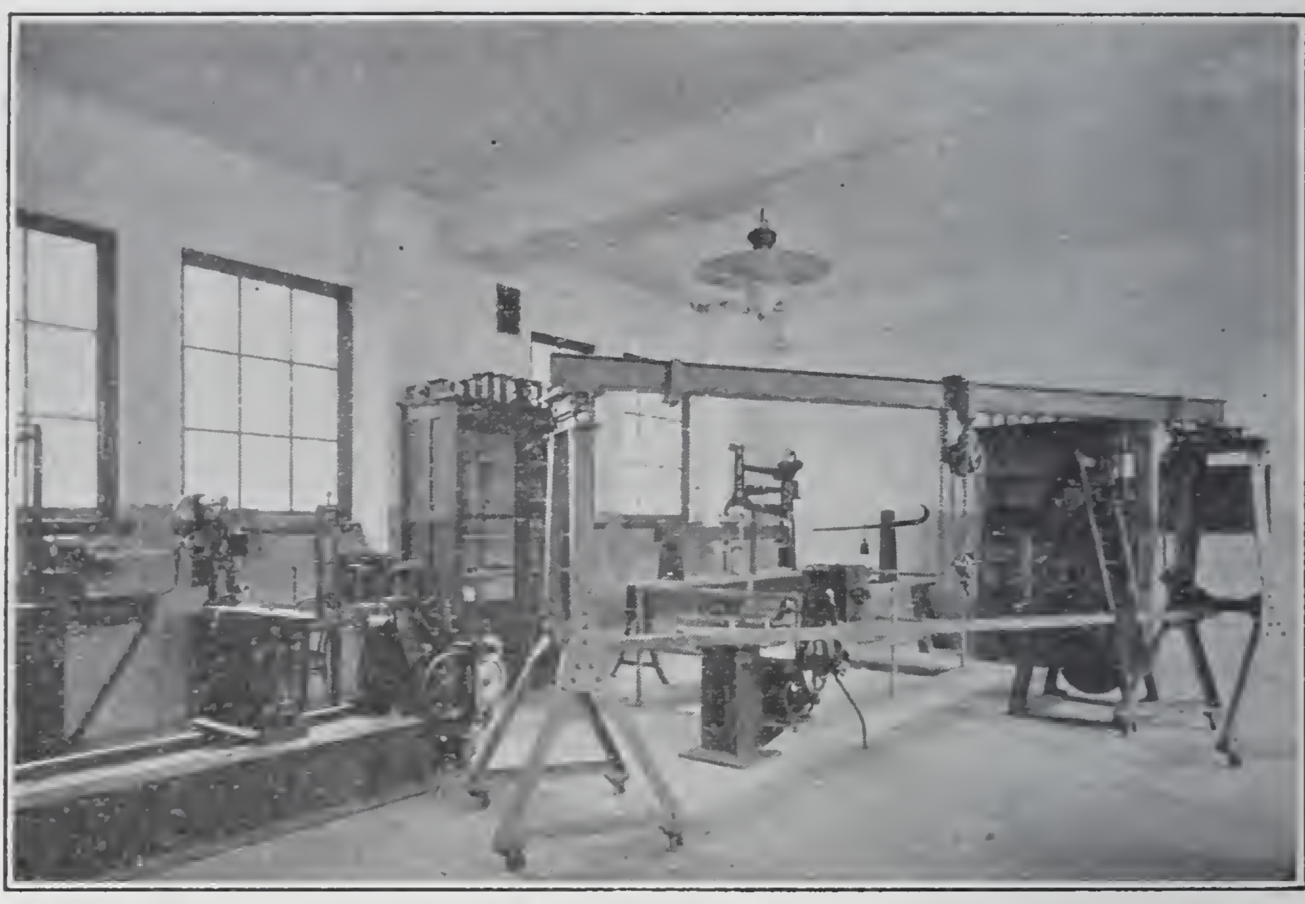


Fig. 17.

Lesley Cement Laboratory.

The fund for the equipment of this laboratory was generously provided by Robert W. Lesley, Esq., of the Class of '71, College. As an expression of their grateful recognition, the University authorities have named the laboratory after the donor and have placed on its walls a bronze tablet bearing the following inscription:

LESLEY CEMENT LABORATORY
Equipped by
Robert W. Lesley, Esq.,
Class of '71, College.
In recognition of the growing needs of a great industry.

This laboratory occupies a floor space of about 1700 square feet and is divided into two parts by a paneled oak partition. The larger room is devoted to instruction in the standard tests of cement. The smaller room is especially equipped for concrete work and is used also as a research laboratory.

The larger room contains four large slate-top mixing tables (Fig. 11) each accommodating four students. Each table is supplied with a damp-closet subdivided into four sections, four lockers and drawers for the storage of apparatus needed for routine tests, and two balances placed on a raised shelf along the center of the table. The waste is conveniently discharged through chutes provided for that purpose. Graduated burettes of a capacity of 360 c.c. are mounted between these tables, connected to a water tank through which water at normal temperature may be accurately and quickly obtained. The lower parts of these burettes are made of a smaller diameter than the upper part, thus permitting of the more accurate gaging of smaller quantities of water.

A large slate-top table, supplied with gas outlets, is used for mounting smaller apparatus and affords space for special experimental work.

The testing apparatus in this room (Fig. 11) consists of an Olsen and a Riehle lever machine, a Fairbanks and a Falkenau-Sinclair machine of the shot type, and a 50,000-pound hand-power hydraulic machine for compression tests. The lever machines are driven by independent electric motors and are designed to admit of the application of the load at a uniform rate varying from 100 to 600 pounds a minute.

This room is also equipped with an Olsen mechanical briquette-moulding machine, a Howard and Morse automatic sifting apparatus for cement and sand, and a Bauschinger expansion apparatus.

Nine soapstone immersion tanks, variously subdivided and supported on steel frames in three tiers, are piped for hot and cold water, so that a mixed flow may be supplied at any desired temperature, and are in part provided with adjustable overflow discharge connections for maintaining a continuous flow of water at a variable rate. One of these tanks is supplied with 32 small, three-shelved zinc racks for the storage of briquettes.

A large soapstone damp closet is provided in this room divided into two compartments for the accommodation of the larger briquette and beam moulds. A series of cement bins and briquette racks are ranged along one of the walls, each bin having a capacity of one

barrel of cement, and the racks, which are subdivided and numbered for the convenient classification of their contents, provide accommodation for several thousand briquettes. The room contains a large case for the storage of glassware and special apparatus.

The laboratory is equipped with a very complete outfit of smaller apparatus, including balances of various degrees of sensitiveness, specific gravity apparatus, briquette moulds, etc.

A glass-enclosed office overlooks this room and the adjoining research laboratory. The latter is equipped with one standard mixing table and its full complement of apparatus. It contains the boiling

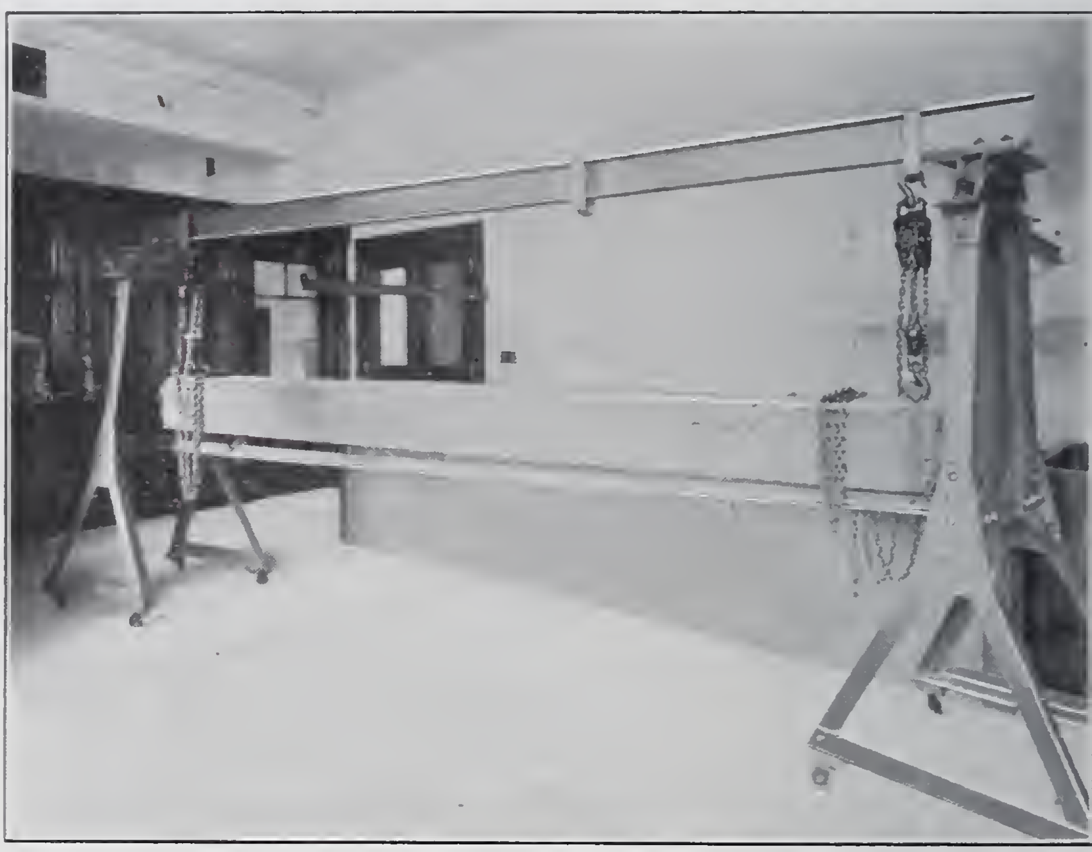


Fig 18.—Concrete-beam Crane and Large Immersion Tank, in Lesley Cement Laboratory.

apparatus for accelerated tests, mounted on an iron stand, and a drying oven for use in connection with specific gravity and absorption tests.

A large concrete immersion tank (Fig. 13) capable of accommodating concrete beams 13 feet long is installed in this room and provided with a special beam crane for the convenient handling of the beams and their transference to special carrying frames mounted on casters designed for their transportation to a 200,000-pound Olsen universal machine, with permanent table for transverse tests, installed in the laboratory just across the hall.

A concrete block of suitable height for moulding compression specimens is provided in one corner of the room. Above this block,

and back of it, is a case of shelving for the storage of the moulds used in that connection.

Several bins for the storage of stone and sand are provided, as well as a wooden mortar box for mixing concrete. This laboratory is further equipped with moulds for making 8- by 11-inch beams, 13 feet long, and 8- by 8-inch beams, 9 feet long.

For the convenient transportation of material to the laboratory a lift with a capacity of 1200 pounds is installed and furnished with a steel car, mounted on a truck.

The 200,000 pounds universal machine (Fig. 9) previously referred

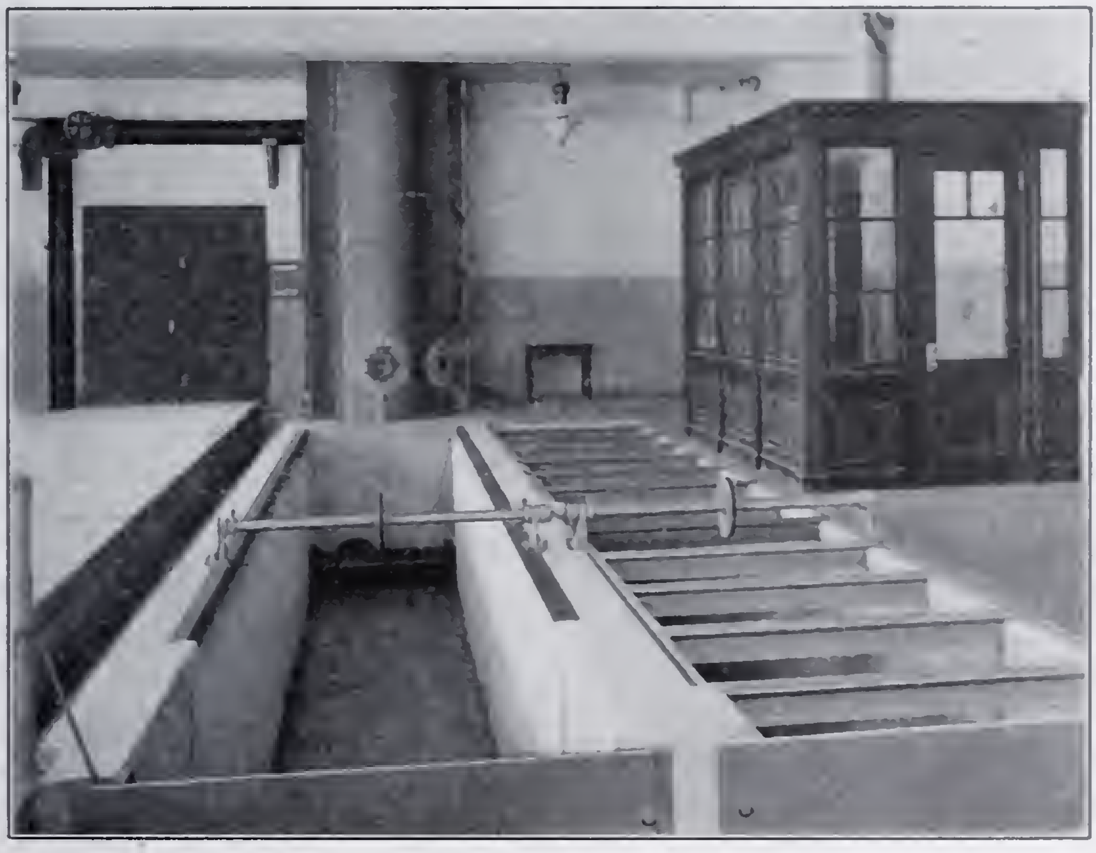


FIG. 19.—WEIR TANKS AND PRESSURE TANK. HYDRAULIC LABORATORY, FIRST FLOOR.

to, which forms part of the equipment of this laboratory though installed in an adjacent room, is an Olsen three-screw vertical machine fitted with a beam extension 15 feet long designed for a working load of 120,000 pounds. It is operated by a direct-connected 5 H. P. two-speed electric motor, and is equipped with an autographic attachment for recording stress-deformation diagrams.

The Hydraulic Laboratory.

The Hydraulic Laboratory occupies a spacious room in the basement and directly overhead on the first floor and a small room on the second floor, and covers a total floor area of about 5300 square feet.

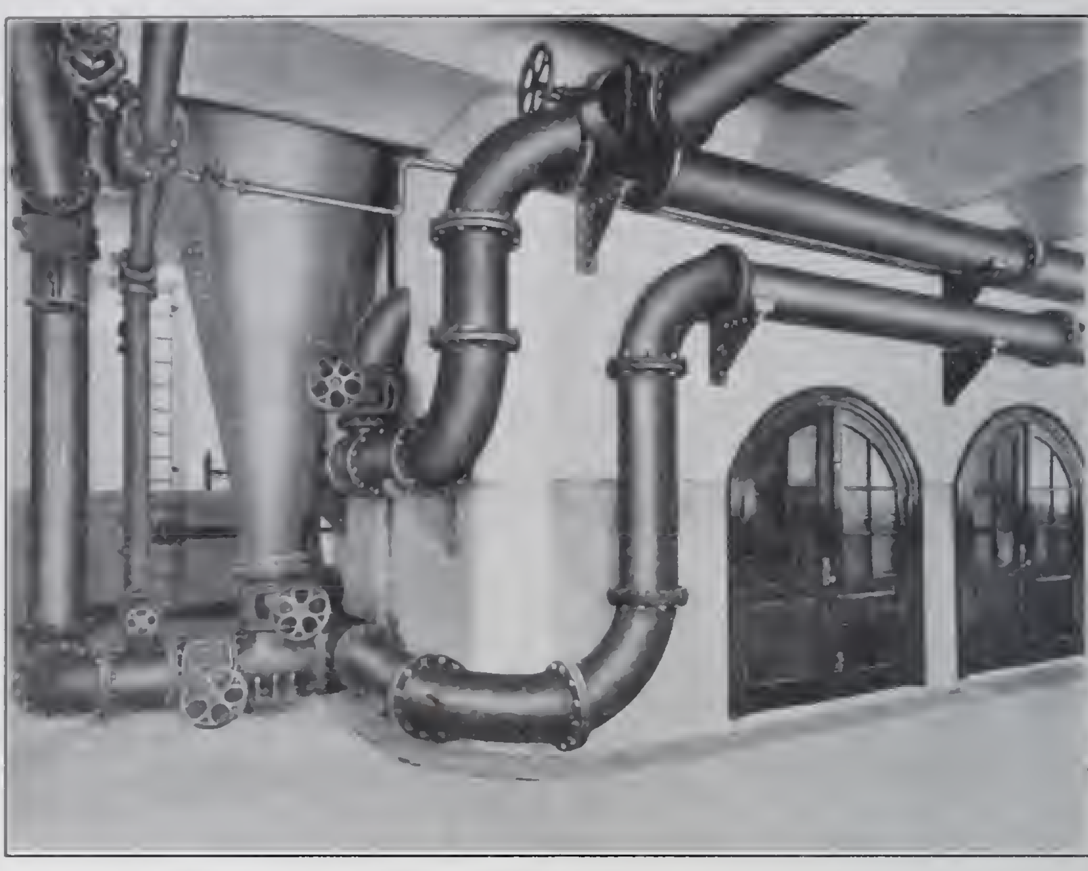


Fig. 20.—Conical Bottom Section of Pressure Tank; Stand-pipe and Piping System, and Basement of Hydraulic Laboratory.

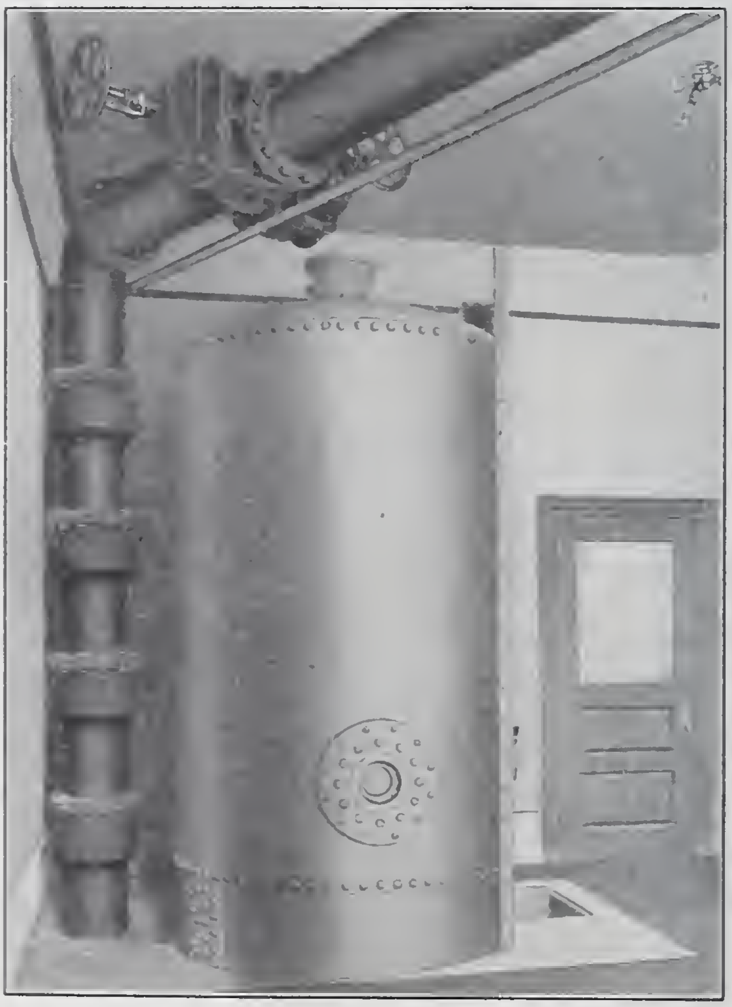


Fig. 21.—Stand-pipe and Upper End of Pressure Tank, Second Floor.

This laboratory contains a circular vertical steel pressure tank 5½ feet in diameter and 37 feet high (Figs. 14, 15, and 16), which extends from the basement floor to the second-story ceiling. This tank is provided with orifice devices so designed as to permit of changes in the orifice plates while the tank is under pressure. The tank is proportioned for a maximum working pressure of 65 pounds per square inch, corresponding to a head of water of about 150 feet above the center of the lower orifice. The piping is so arranged that the tank may be brought under the pressure of the city mains, under

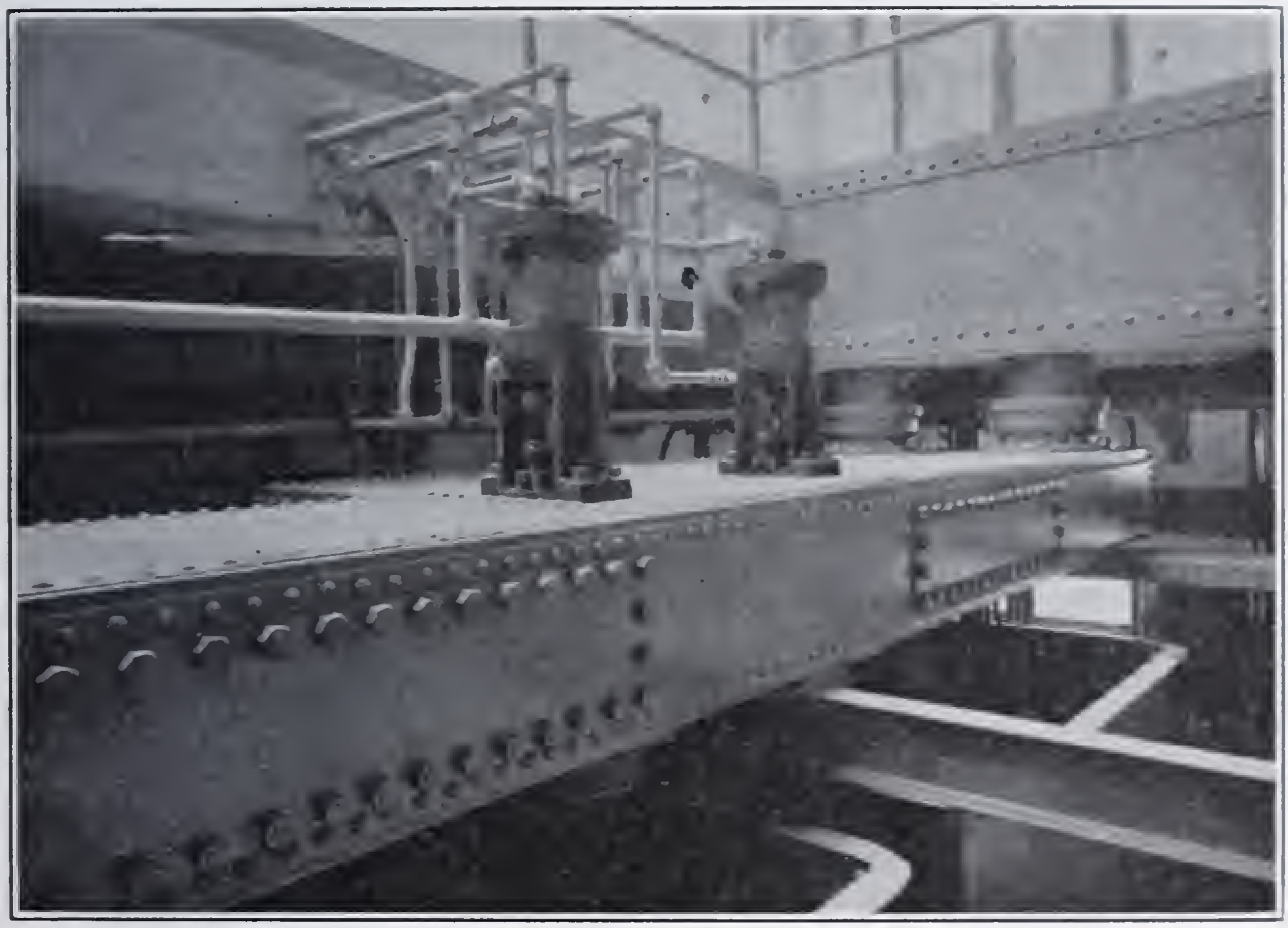


FIG. 22.

the pressure of the water in a stand-pipe, extending a few feet above the roof of the building, or under higher pressures by direct pumping.

The discharge from the lower orifice of the pressure tank passes into one of two large weir tanks constructed of reinforced concrete (Fig. 14). These tanks are each 34 feet long and 5 by 5½ feet in cross-section. They are fed at one end through cast-iron pipes with numerous perforations arranged with a view of breaking up the current, which is further accomplished by baffle screens. The two tanks are connected by a sluice gate so that they may be used jointly as a single large calibrated measuring tank of 13,000 gallons capacity.

The arrangement of the weir plates at the extremities of these tanks is designed so that weirs with and without end contractions may be obtained as well as discharges through orifices under low heads. The lowest section of these plates is hinged, and by swinging it down the tank may be converted into a canal, across which dams of varying profiles may be placed for investigations on the flow over their crests. A conveniently arranged gaging pit is provided for determining the height of water on both weirs, by means of hook gages.

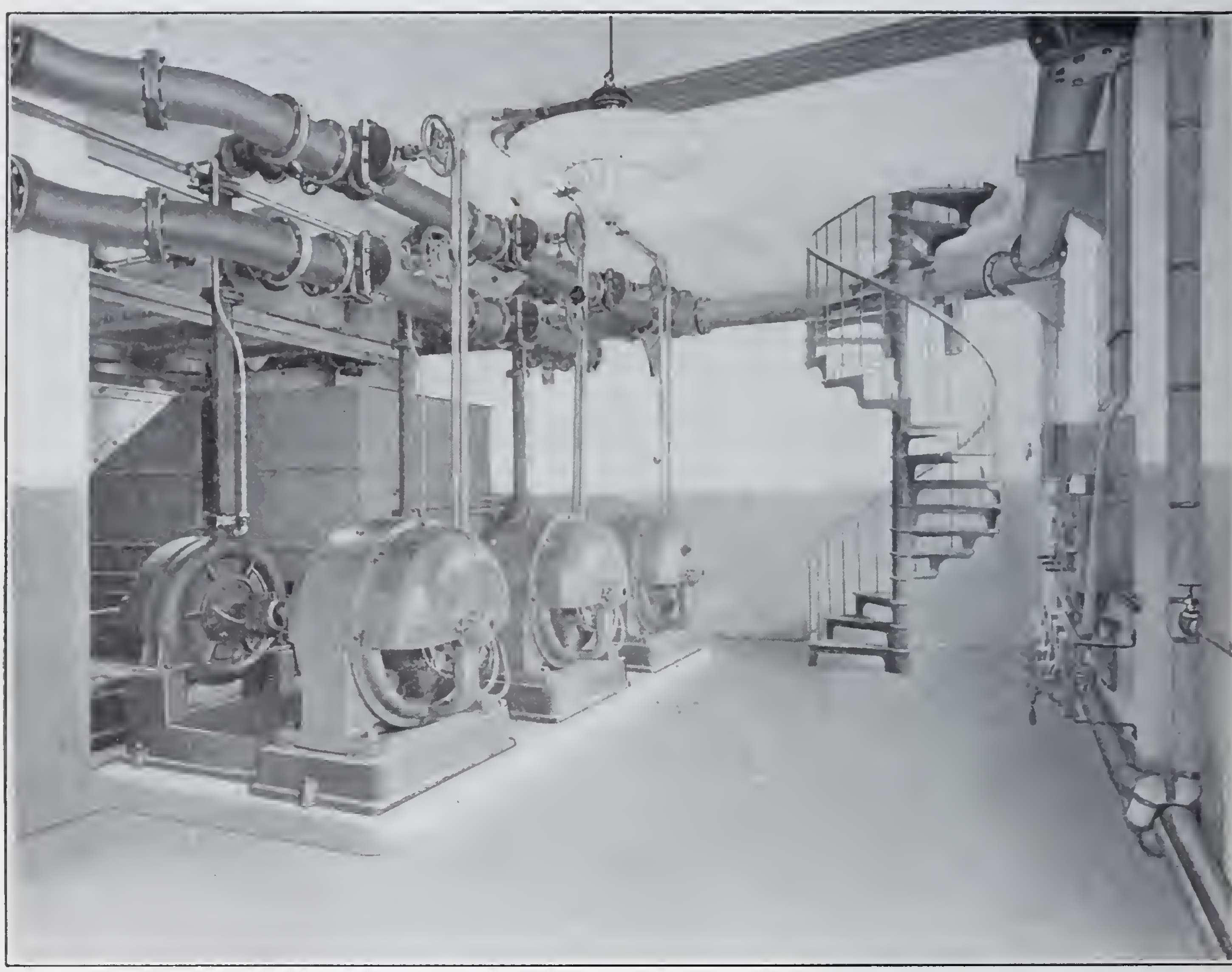


Fig. 23.—Two-stage Electrically Driven Centrifugal Pumps; Overhead Chutes and Weighing Tanks. Basement, Hydraulic Laboratory.

The discharge from the weirs leads directly to a pumping reservoir of reinforced concrete with a capacity of 23,000 gallons. Provision is made for weighing all water from apparatus; it then passes into this reservoir. This is accomplished by diverting the flow into a permanently mounted steel chute provided with a pair of valves operated by quick-action hydraulic lifts (Fig. 17), opened alternately and discharging into a pair of steel tanks (Fig. 18) mounted

on scales. Each of these tanks has a working capacity of 1800 gallons. The water is discharged from these tanks into the pumping reservoir through quick-discharge valves, thus permitting of alternate weighings of a continuous flow of water.

From the main reservoir the water is pumped by three Worthington 4-inch two-stage pumps (Fig. 18), each driven by a 35 H. P. electric motor with a wide range of speed. Each pump has a capacity of 450 gallons per minute against a maximum head of 165 feet. For lower heads considerably larger discharges may be obtained. These

Fig. 24.

pumps may be operated singly or in series, and a close approach to uniformity of head is obtained by wasting from the supply-pipe leading to a given piece of apparatus.

An important feature of the installation in this laboratory is a stand-pipe 12 inches in diameter and 65 feet high extending from the basement floor to a short distance above the roof of the building, connecting with the main pipe circuits and with the pressure tank at top and bottom (Fig. 16). Circular overflow weirs are provided at frequent intervals in the stand-pipe so that by suitable regulation of valves any piece of apparatus may be connected to the stand-pipe

and subjected to a constant static head of predetermined height up to 65 feet. For greater pressure, connection must be made with the pressure tank, as previously stated, or directly with the pumps.

In a corner of the main pumping reservoir a water-tight 8-inch tubular well 110 feet deep is provided for efficiency tests and general experimental work with air-lifts and deep-well pumps.

Circuits of 10-inch cast-iron pipe are supported on iron wall brackets near the basement and first floor ceilings. At intervals along these circuits provision is made for the attachment of apparatus. The system as a whole is carefully planned so as to admit of conducting a variety of experiments concurrently without interference.

Covered concrete gutters extend the entire length of the laboratory, both on the basement and first floor, to carry the discharge from minor apparatus to the pumping reservoir. The outlets from the gutter on the first floor are connected to the steel chutes above the weighing tanks, thus admitting of the weighing of the discharge before it enters the pumping reservoir.

The laboratory is equipped with a 9-inch turbine and a 12-inch reaction wheel, suitably mounted to permit of efficiency test, an assortment of water meters representative of all the leading types, and a great variety of minor apparatus.

Geodetic Laboratory.

The Geodetic Laboratory (Fig. 19) occupies a spacious, well-lighted room in the basement, which, at this point, lies entirely above the ground level. The surveying instruments are housed in this room within easy access of a side exit to the street. The equipment consists of a large assortment of instruments used in ordinary engineering practice and a variety of instruments of greater precision, employed in geodetic surveying.

The equipment comprises one 10-inch theodolite reading to single seconds by micrometer microscopes; two triangulation and one city transit reading to twenty seconds: 14 engineer's transits; 2 precise levels; 4 dumpy levels; 8 wye levels; 4 plane tables; 4 compasses; 4 sextants, and a large assortment of miscellaneous apparatus, such as mercurial and aneroid barometers, prismatic compasses, pocket sextants, clinometers, passometers, hand levels, planimeters, level triers, pantograph, curvograph, trigonometer, collimator, slide rules, railroad curves, tape testing apparatus, stadia sketching tables, stadia and level rods, range poles, chains, tapes, pins, etc.

The apparatus is distributed in a series of closets with glass fronts, each closet accommodating the outfit for a separate surveying party, thus admitting of the prompt and orderly distribution of the equipment among a large number of students. Piers and large tables are provided for indoor work, especially in inclement weather.

Paper No. 1029.

THE DESIGN AND CONSTRUCTION OF A REINFORCED CONCRETE APARTMENT HOUSE.

H. G. PERRING.

Read October 6, 1906.

The subject of reinforced concrete is one of such lively interest that architects and engineers generally are giving it great attention. On every hand we see buildings of this construction being erected, and every technical periodical devotes many columns to the description of work being carried out in which this form of construction is used. Theories galore are to be found, treating the subject of stress in concrete, stress in the steel, shearing stress, tensile stress, compressive stress, etc. Some of these theories are so complex as to befog the mind of the practising engineer who has some time since forgotten the use of the $\frac{dy}{dx}$; or the integration sign—and, it may be added, even Greek letters—while others are apparently too simple to give safe results under all conditions. As doubtless many are interested in the subject, but have not the time to go deeply enough into it to realize its simplicity, the general principles governing safe design are presented.

The external stresses are figured exactly as in the construction of steel or wood. Having then the external stresses it is necessary to secure resistance in the material of construction to equal the external forces.

We are limited, in the larger cities of the country, to certain stresses in material. Thus in Philadelphia 500 pounds per square inch is the maximum allowed fiber stress in concrete, and 16,000 pounds per square inch is the maximum allowed fiber stress in steel. With these limitations, and the general theory of beams that the stress in the compressive and tensile areas shall be equal; that within the elastic limit a plane section before bending shall remain a plane section after bending, and, further, that the concrete and steel shall have such intimate relation that they act together, and that the tension in concrete shall be neglected, we are prepared to proceed with design.

The first step in the design of a reinforced concrete beam is the location of the neutral axis. The materials of construction follow, approximately at least, Hookes' law—that of proportionality of stress and strain.

Calling maximum fiber stress in concrete fc and unit stress in steel fs, the modulus of elasticity of concrete Ec and that of steel Es, we see that the deformation in the outermost compressive fiber will be $\frac{fc}{Ec}$, while the deformation in the tension fiber will be $\frac{fs}{Es}$.

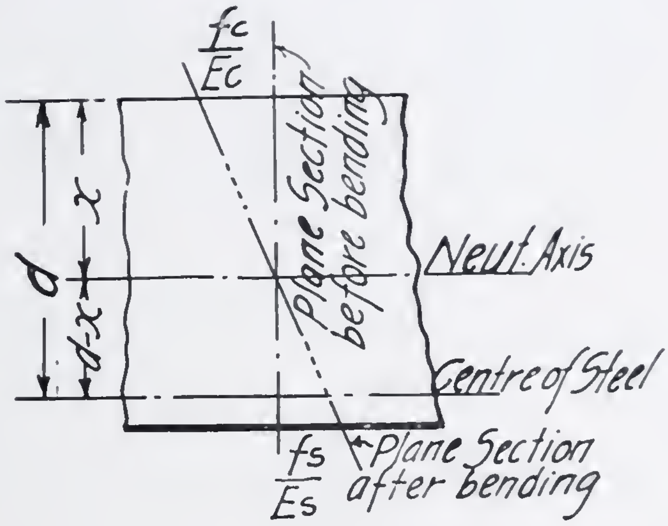


Fig. 1.

Calling the distance from top of beam to center of steel d, the distance from top of beam to neutral axis x, and from neutral axis to center of steel $(d—x)$, we have, considering the deformed section still a plane, two similar triangles, with sides $\frac{fc}{Ec}$ and x, and $\frac{fs}{Es}$ and $(d—x)$, from which

$$\frac{fc}{Ec} : \frac{fs}{Es} : : x : (d-x)$$

or

$$\frac{fcEs}{fsEc} = \frac{x}{(d-x)}$$

or

$$(1) \qquad x = \frac{Esfc}{Ecfs}(d-x)$$

The stress in concrete and steel must be equal. If we are considering a beam twelve inches wide,

$$(2) \qquad fsAs = 12fc\frac{x}{2}$$

where As equals area of steel reinforcement.

From which

$$(3) \qquad As = 6x\frac{fc}{fs}$$

Provided we consider the stress in concrete to vary uniformly from zero at neutral axis to a maximum at the extreme fiber, as a straight line, we find the center of pressure will be at a distance $\frac{x}{3}$ below the top of beam. The lever arm of the couple stress in steel and stress in concrete is the distance $d-\frac{x}{3}$ from which we see the moment of resist-

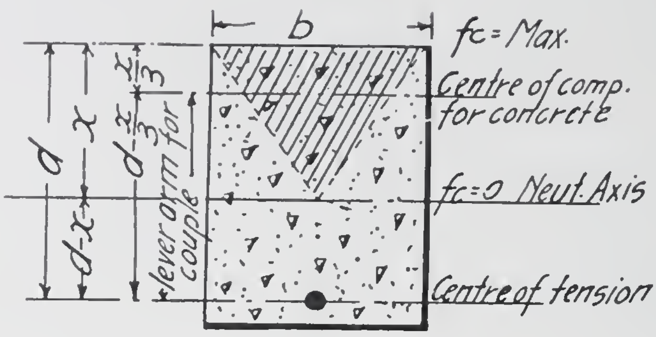


Fig. 2.

ance Ms of the steel:

$$(4) \qquad Ms = fcAs\ (d-\frac{x}{3})$$

while the moment of resistance of the concrete Mc is

$$(5) \qquad Mc = 6fcx\ (d-\frac{x}{3})$$

We now have all the equations required to design a beam for moment. By inserting the values allowed for stress in steel and concrete, and the moduli of elasticity of steel and concrete, the numerical values may be secured. It is, of course, understood that if a numerical value has been substituted in one formula it cannot be changed in another in any particular case under consideration.

REINFORCED CONCRETE.

U. S. Navy Dpt. Bureau of Y. ED. Formula.

1. $fsAs = 12fc\frac{x}{2}$
2. $As = 6x\frac{fc}{fs}$
3. $\frac{fs}{d-x} = \frac{fc}{x} \cdot \frac{Es}{Ec}$
4. $\frac{x}{d-x} = \frac{fc}{fs} \cdot \frac{Es}{Ec}$
5. $M = fsAs\left(d-x + \frac{2x}{3}\right)$
6. $M = 6fcx\left(d-\frac{x}{3}\right)$
7. $x = d-x\left(\frac{fc}{fs} \cdot \frac{Es}{Ec}\right)$

fs = Unit tensile str. of steel.
fc = Unit comp. str. of concrete.
x = Dist. from comp. flange to neutral axis.
As = Area steel.
M = Moment of section 12 inches wide in inch lbs.

	Stress in Steel.	x.	As.	M.	Per Cent. d.
	16,000	.238 d	.0447 d	658 d^2	.37
	15,000	.250 "	.0500 "	688 "	.42
	14,000	.263 "	.0563 "	720 "	.47
	13,000	.278 "	.0641 "	756 "	.53
	12,000	.294 "	.0735 "	796 "	.61
	11,000	.313 "	.0854 "	841 "	.71
$\frac{Es}{Ec} = 10$	10,000	.333 "	.1000 "	889 "	.83
	9,000	.357 "	.1190 "	944 "	.99
	8,000	.385 "	.1442 "	1006 "	1.20
	7,000	.417 "	.1786 "	1076 "	1.49
	6,000	.455 "	.2272 "	1157 "	1.90
	5,000	.500 "	.3000 "	1250 "	2.50
	4,000	"			

Unit stress in concrete 500 sq. ft.

	Stress in Steel.	x.	As.	M.	Per Cent. d.
	16,000	.273 d	.0510 d	744 d^2	.43
	15,000	.286 "	.0572 "	776 "	.48
	14,000	.300 "	.0643 "	810 "	.54
	13,000	.316 "	.0730 "	848 "	.61
	12,000	.333 "	.0833 "	889 "	.69
	11,000	.353 "	.1023 "	934 "	.85
$\frac{Es}{Ec} = 12$	10,000	.375 "	.1125 "	984 "	.94
	9,000	.400 "	.1336 "	1040 "	1.11
	8,000	.428 "	.1618 "	1110 "	1.35
	7,000	.462 "	.1981 "	"	1.65
	6,000	.500 "	.2502 "	1250 "	2.08
	5,000	.545 "	.3279 "	"	2.73
	4,000	.600 "	.4500 "	1440 "	
	16,000	.319 d	.0598 d	856 d^2	.50
	15,000	.333 "	.0667 "	889 "	.56
	14,000	.349 "	.0748 "	925 "	.62
	13,000	.366 "	.0860 "	964 "	.72
	12,000	.385 "	.0962 "	1006 "	.80
	11,000	.405 "	.1106 "	1052 "	.92
$\frac{Es}{Ec} = 15$	10,000	.429 "	.1286 "	1102 "	1.07
	9,000	.454 "	.1515 "	1157 "	1.26
	8,000	.484 "	.1815 "	1218 "	1.51
	7,000	.517 "	.2217 "	1284 "	1.85
	6,000	.556 "	.2778 "	1360 "	2.32
	5,000	.600 "	.3600 "	1445 "	3.00
	4,000				

x = Distance from top of concrete to neutral axis.
d = Depth from top of concrete to c. steel.
As = Area of steel.
M = Moment of section in inch lbs., beam 12 inches wide.
Unit stress in concrete 500 sq. ft.

	Stress in Steel.	x.	As.	M.	Per Cent. d.
$\frac{Es}{Ec} = 20$	16,000	.385 d	.0721 d	1006 d^2	.60
	15,000	.400 "	.0800 "	1040 "	.67
	14,000	.417 "	.0893 "	1076 "	.74
	13,000	.435 "	.1003 "	1115 "	.84
	12,000	.455 "	.1136 "	1157 "	.95
	11,000	.476 "	.1299 "	1202 "	1.08
	10,000	.500 "	.1500 "	1250 "	1.25
	9,000	.526 "	.1754 "	1302 "	1.46
	8,000	.556 "	.2083 "	1358 "	1.37
	7,000	.588 "	.2521 "	1419 "	2.10
	6,000	.625 "	.3125 "	1484 "	2.61
	5,000	.667 "	.4000 "	1556 "	3.34

Unit stress in concrete 500 sq. ft.

	Stress in Steel.	x.	As.	M.	Per Cent. d.
$\frac{Es}{Ec} = 40$	16,000	.385 d	.0360 d	503 d^2	.30
	15,000	.400 "	.0400 "	520 "	0.33
	14,000	.417 "	.0447 "	538 "	.37
	13,000	.435 "	.0502 "	558 "	.42
	12,000	.455 "	.0568 "	579 "	.47
	11.000	.476 "	.0649 "	601 "	.54
	10,000	.500 "	.0750 "	675 "	.63
	9,000	.526 "	.0877 "	651 "	.73
	8,000	.556 "	.1041 "	629 "	.87
	7,000	.588 "	.1261 "	710 "	1.05
	6,000	.625 "	.1563 "	742 "	1.30
	5,000	.667 "	.2000 "	778 "	1.67

Unit stress in concrete 250 sq. ft.

The area of concrete is $12d$; the area of steel is As; the ratio of steel to concrete is $\frac{as}{12d}$, from which the percentage is secured by pointing off two places. For any definite percentage of steel in a beam the relation between stress in steel and stress in concrete is constant and cannot be varied.

For convenience in design some tables allowing different values for the ratio of the moduli of elasticity of concrete and steel have been worked out.

The ratio allowed by the Philadelphia Bureau of Building Inspection is 20 for stone concrete and 40 for cinder concrete. These tables give in terms of the depth d the distance of the neutral axis from top of beam, the area of steel, and the moment of resistance of the section,

based upon different percentages of steel or different stress in steel, the stress in the concrete remaining constant.

Columns also are designed by applying Hooke's law.

The deformation of concrete and steel must here be the same, so that any amount of steel must be converted into concrete by multiplying the area of steel by the ratio of the moduli of elasticity. In Philadelphia the ratio of moduli of elasticity is taken at 20. Recent experiments have shown that a ratio of 10 is more nearly the proper one, but the Philadelphia Building Department avoids all discussion of the matter by ruling that the concrete alone shall be considered, and the value of the steel not considered.

It is thus seen that the design of reinforced concrete is a simple matter, and that the most complex designs may be worked out if the external stresses are definitely determined and due regard is paid to the relative deformation of the two materials.

The reinforced concrete apartment house referred to in the title is now in the course of erection at Juniper and Spruce streets, Philadelphia; McIlvain & Company, owners; McIlvain & Roberts, architects; Metzger & Wells, general contractors; J. W. Allison & Co., engineers and contractors for reinforced concrete; and the Keystone Fireproofing Company, contractors for fireproof partitions.

The building is 40 feet by 127 feet; eight stories and basement; fireproof throughout by reinforced concrete frame and floors, and plaster-block partitions.

Reinforced concrete construction was decided upon when it was found upon opening bids that the cost of a reinforced structure was less than that of steel frame alone without fireproofing.

The most interesting features of the concrete design are the cantilever balconies; the cantilever construction at the stair-well; the setting back of center of columns to fit in with partitions, and the type of floor construction. The cantilever balcony with its brick parapet wall is, to the mind of the layman, a wonderful thing—a thin slab without brackets supporting such a weight on its outer edge. From an engineering standpoint, however, there is nothing out of the ordinary, the stresses being simply reversed, with tension members at the top instead of the bottom and the rods tying back into the beams of the floors.

The cantilevers around the stair-well are more serious from an engineering view, but are taken care of in like manner. The columns are set back to give a straight corridor line of the same width on each

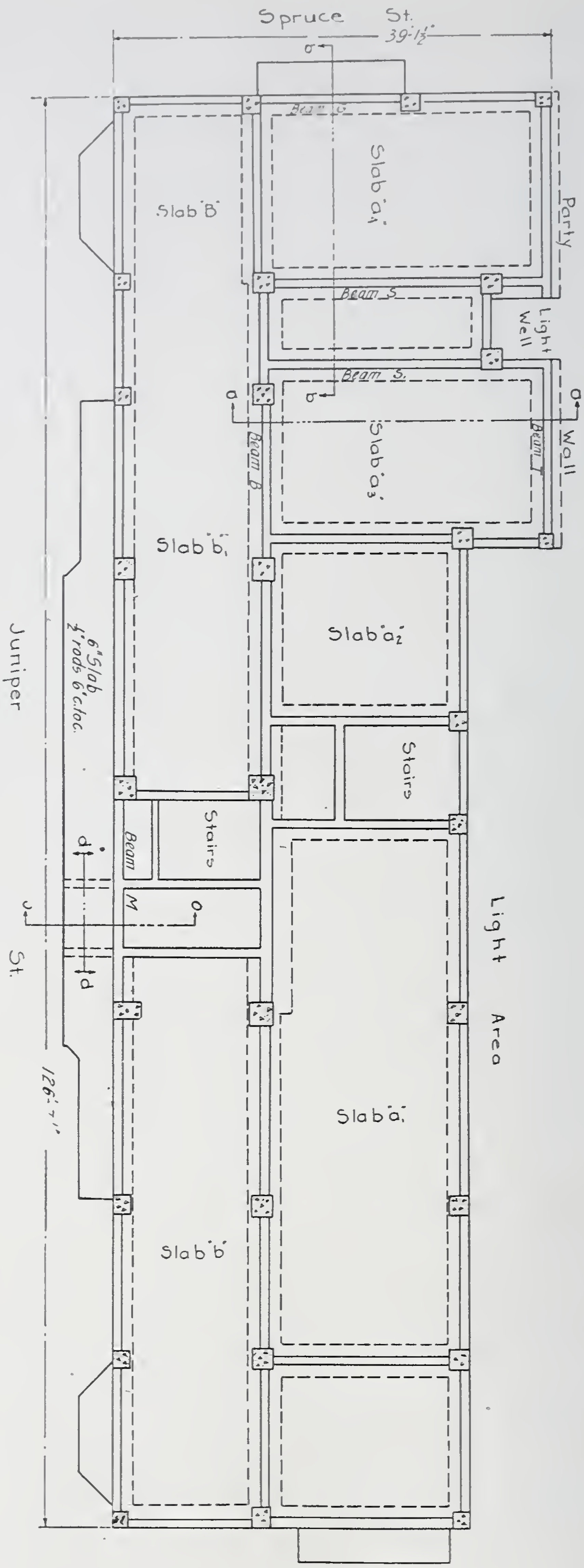

Spruce St.
Slab "B"
Slab "a₁"
Party
Light Well
Beam S
Beam S
Wall
Beam B
Slab "b₁"
Juniper St.
Slab "a₂"
Stairs
Stairs
Beam
Light Area
Slab "a"
Slab "b"

Fig. 3.

floor, but the center of pressure is almost coincident with the average center of the columns, the little difference being provided for in the design. The main line of girders inside the corridor does not center exactly on the columns, but here again the design is such that the unequal stresses are taken care of.

The walls of the top story are of concrete, plastered to give a pleasing contrast to the brick used in the main body of the building. These walls are hollow, 18 inches thick, with 6 inches of concrete inside and outside, and a four-inch air space. An attempt was first made to build the hollow walls with movable wooden forms inside, but an

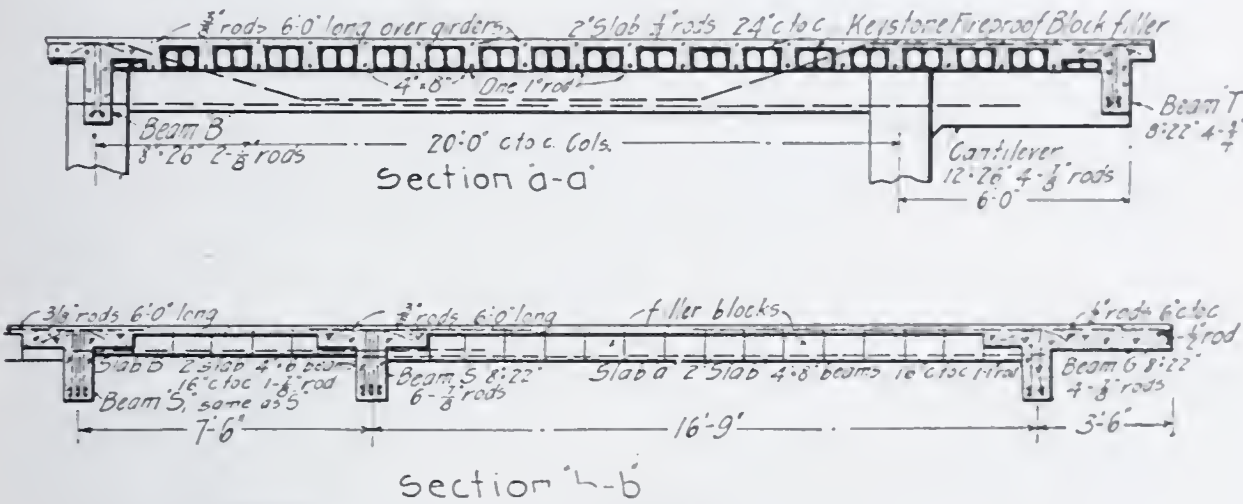


FIG. 4.

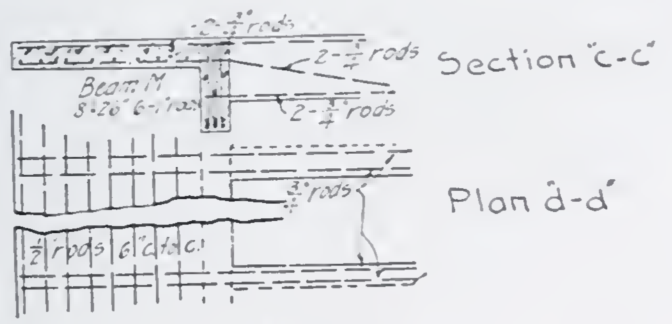


FIG. 5.

experiment proved that the time and labor saved in using hollow plaster block to form the core in the concrete wall well paid for the extra cost of material, and gave results, from a damp-proof standpoint, equal to the dead air space. These blocks were, therefore, used to complete the work. The type of floor construction is rather unique.

The construction originally intended to be used was a flat slab of concrete extending between main beams. This type was abandoned, and a construction of beams 4 inches wide, 16 inches c. to c., and 6 inches to 8 inches deep, according to the span, with a two-inch slab

over all, was substituted. As a flat ceiling was required, a filler of plaster block was used. This block was made the required depth,

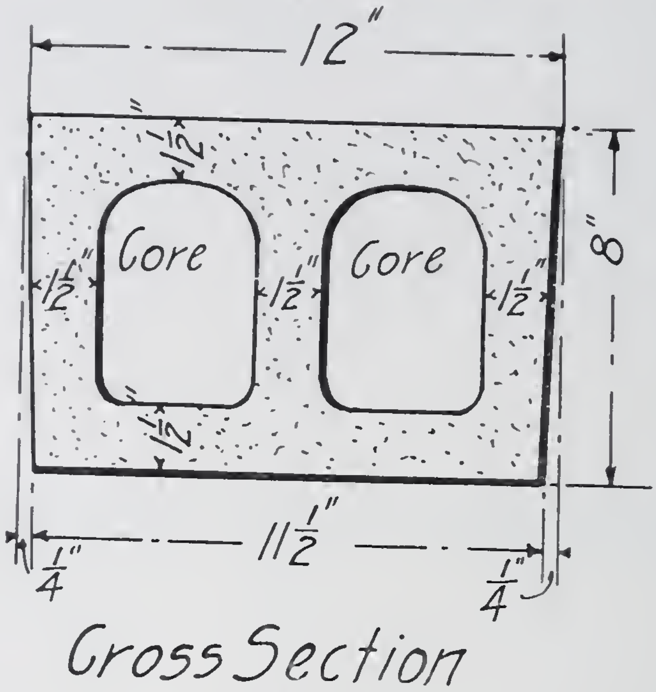


FIG. 6.

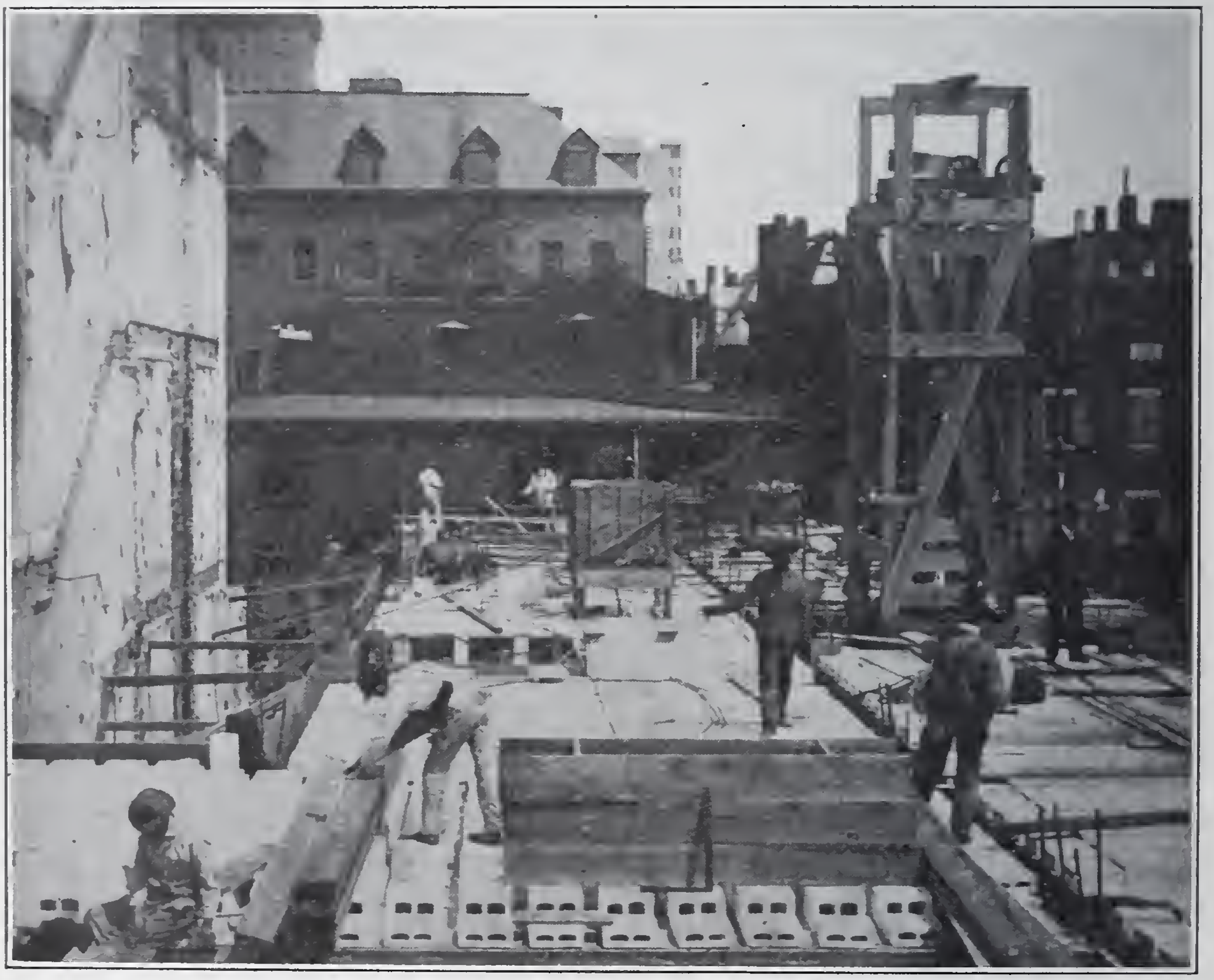


FIG. 7.—FLOOR FILLER BLOCKS PLACED READY FOR CONCRETING.

6 inches or 8 inches, 12 inches wide at the top, and $11\frac{1}{2}$ inches at the bottom. The blocks were laid on the wooden forms which were

spaced 8 inches apart, and thus formed the centers for the sides of the beams and for the floor slab, as shown in Fig. 3; the reinforcing rods were placed on the forms between the blocks, and the whole concreted

FIG. 8.—GENERAL VIEW OF CONCRETE CONSTRUCTION AND FRAMING FOR CONCRETE UPPER WALLS.

in. Upon the forms being removed, a smooth even ceiling was revealed, ready to plaster, upon which only a white coat of plaster was required. The blocks are keyed between the beams by their shape.

It was feared at first that the blocks would crush, or be easily broken by the weight and impact of a loaded wheel-barrow being pushed over them, and strict orders were given that there should be no wheeling over the blocks without first placing planks or runs. This precaution proved useless, for within an hour after work began the wheel of one

FIG. 9.—TEST HOUSE OF 2-IN. PLASTER BLOCK BEFORE FIRE WAS STARTED.

barrow slipped off the run, and was pushed the full length of the row. After that wheeling planks were forgotten when pushing the load in the direction of the lay of the blocks, and the blocks were used to wheel on.

After a short trial it was found that the blocks which had been laid

dry were taking up water from the concrete too rapidly and drying it out before proper set took place. This difficulty was at once overcome by a liberal application of water from a hose.

Fig. 10.—Exterior of Test House of 2-in. Plaster Block at Completion of Test.

Despite the severe treatment of wetting and wheeling of loaded barrows over them there was but 1 per cent. of blocks broken.

There were several considerations which led to the use of plaster block, rather than such a material as terra-cotta, for the floor filler

block, and also for partitions. The plaster block has a coefficient of expansion of about zero (according to Mr. Tassen, assistant curator of the Smithsonian Institute), whereas terra-cotta expands at about

FIG. 11.—INTERIOR OF TEST HOUSE AT COMPLETION OF FIRE AND WATER TEST.

twice the rate of steel (according to Professor Norton), its coefficient of expansion being about .0000130. Hence, in the event of fire, a stretch of ceiling 15 feet wide would have from the terra-cotta alone

in a range of temperature of say 1500° about .3 of a foot expansion, which would correspond to a stress of 900,000 pounds per square inch. As the compressive strength of terra-cotta is about 4000 pounds per square inch, it is seen that failure would ensue before the fire had continued very long.

On the other hand, using plaster block of low conductivity, and with small if any expansion, there would be nothing to fear from expansion. The plaster block is a sound-deadener for the floors, being more efficient for this purpose than any other form of fireproof construction, as shown by tests made by Professor Norton for the New England Conservatory of Music.

The plaster block is also more efficient as a non-conductor of heat. Experiments made by one of the foremost architects in this city demonstrated that concrete placed in forms made of plaster block was much harder than that made in wood, the reason being that while the concrete made in plaster-block forms loses some of the excess water to the block, evaporation takes place so slowly from the block that the concrete is kept moist while setting, giving the effect of hardening under water. Concrete placed in wooden forms hardens in air, as the wood is removed in one or two weeks' time.

The partitions in the building are of plaster block, made by the Keystone Fireproofing Company, and what has been said of the floor-filler block applies to the partition block.

DISCUSSION.

Emile G. Perrot.—As the desire to secure a column of reinforced concrete which shall not occupy too much floor space has of late arisen, due to the desire to build reinforced buildings high, the writer has investigated the results of a number of tests on hooped columns and prepared a formula for their design which he submits herewith.

While it has been the custom to calculate the strength of columns reinforced with longitudinal bars only laced together by the formula based on the moduli of elasticity of the two materials and the area of each material, very little has been accomplished in the deduction of a practical working formula for hooped columns with longitudinal reinforcement.

Considere's theory, which is used as a basis for calculating hooped columns, is as follows:—

The compressive resistance of a hooped member exceeds the sum of the following three elements:—

1. The compressive resistance of the concrete alone.
2. The compressive resistance of the longitudinal bars stressed to their elastic limit.
3. The compressive resistance which would have been produced by imaginary

longitudinals at the elastic limit of the hooping metal, the volume of the imaginary longitudinal being taken at 2.4 times that of the hooping.

In deducing a formula based on the above assumptions it is necessary to take into consideration the bursting pressure or lateral tension, due to the spreading or bulging of the columns near the center when compressed. This can best be understood by the following illustrations:—

If a prism of concrete be loaded as shown in Fig. 1, the prism may shear off diagonally, if loaded to destruction, instead of failing by direct compression of the material, since the tensile strength of concrete is much less than its compressive resistance. To ascertain this shearing stress we may reason as follows:—

Let the sectional area of the prism $=A$, then the unit stress on the cross section $S=\frac{P}{A}$, and the stress on the oblique section B. B, making an angle a with the cross-section, may be found thus:—Resolve P into components—normal $N=P \cos a$ and tangential $T=P \sin a$.

The area of the oblique section $BB = A_1 = \frac{A}{\cos a}$

The normal stress $= \frac{N}{A_1} = \frac{P \cos a}{\frac{A}{\cos a}} = \frac{P \cos^2 a}{A}$

Tangential or shearing stress $= \frac{T}{A_1} = \frac{P \sin a}{\frac{A}{\cos a}} = \frac{P \cos a \sin a}{A} = S \cos a \sin a$

As tests on concrete prisms show that the angle of shear is about 60°, the shearing stress at this angle would be $S \times .5 \times .86 = .43S$. But as the column is hooped the horizontal component of this shearing stress will have to be resisted by the hoops; this is therefore the bursting pressure which we will call X and is found to be $\cos a \times$ the shearing stress, or $X = .5 \times .43S = .215S$ when $a = 60°$.

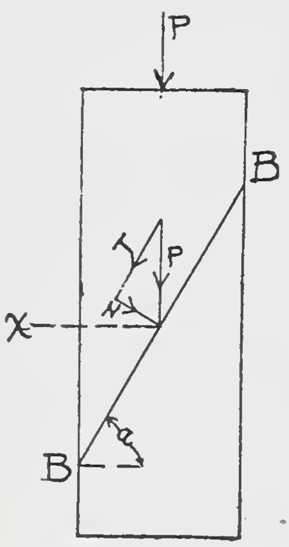


FIG. 12.

In order to derive a simple formula for use in designing hooped columns it is assumed that the column as a whole will sustain a safe load of from 1000 to 1400 pounds per square inch, according to the richness of the concrete, and dividing the load to be carried by the safe working stress will give the area of the column within the hooping, sufficient thickness of concrete being allowed over the hooping for fire protection.

Having determined the size of the column the area of the longitudinal rods near the outside of the column can be obtained by taking 2 per cent. of the area of the concrete core as the area of these rods.

The area of the hooping metal and spacing can be found as follows:—Subtract from the total load on the column the resistance of the outside longitudinal rods figured at a unit stress of 12,000 pounds per square inch; divide this dfference by the area of the column core, which will give the unit stress on the concrete; the unit bursting pressure will equal .215 × this stress; assume the spacing of the hoops to be one-seventh or one-eighth the diameter of the column and multiply one-half the diameter of the column core by the distance on centers of the hoops and by the unit bursting pressure and divide this product by the safe working stress of the material of the hoops and the quotient will be the area of the hoops. Very frequently more

than 1 per cent. of longitudinal rods will be required, especially for high buildings and where the size of the columns must be kept down to within small dimensions. In these cases the additional rods may be located near the center of the column and their size be determined by allowing the same working stresses on them as are allowed on the other longitudinal rods.

The above rule for designing hooped columns compares very favorably with the results of tests made by M. Considere and it has been used in designing a six story building now in course of erection.

Example.—A hooped column, composed of concrete mixed in the proportion of 1.1 and 2, is to carry a load of 355,600 pounds; divide this load by 1400 pounds, and we have 254 square inches for the area of the core, or 18 inches to the outside of the hoops; adding 2 inches on each side for fireproofing, we have a total area for the column of 380 square inches.

Take 2 per cent. of 254 for the area of the outside longitudinal rods; this equals 5 square inches; using eight rods we find that eight one-inch rods equal 6.26 square inches, which size we will use; the resistance of these rods at 12,000 pounds per square inch equals 75,360 pounds; deduct this from the total load on the column, and we have 355,600 pounds minus 73,360, equals 280,240 pounds; divide this by 254 square inches, equals 1103 pounds per square inch on the core. The unit bursting pressure will equal .215 times 1103 pounds, equals 237 pounds. The spacing of the hoops equals one-seventh of 18 inches, or 2.5 inches approximately. The stress on one hoop or spiral equals $\frac{18}{2} \times 2.5 + 237$ pounds, which equals 5332 pounds. If we use a steel of 100,000 pounds ultimate strength, we can safely use a unit stress of 25,000 per square inch on the hoop. This would require $\frac{5332}{25000} = .21$ square inches to each hoop, or approximately a $\frac{9}{16}$-inch round hoop. The same diameter column can be made to sustain a much larger load by adding additional steel longitudinal rods in the body of the concrete as core rods. For instance, if 22 square inches additional were added to the column at 12,000 per square inch, the carrying capacity of the column would be increased 264,000 pounds, or a total of 619,600 pounds. This would make the column have a total of about 7 per cent. of steel in the longitudinal rods in relation to the total area of the column.

G. Edward Smith.—The paper does not give any information regarding the kind of concrete used. In my opinion a slow hardening concrete is preferable; otherwise if any of the stone is shifted after being in place a few moments the cohesion between the stone and cement is destroyed, for after cement is partially set if the bond be broken it will no longer adhere to stone. On this account there is always danger of a flaw in this class of work which may prove disastrous. It would be interesting to know Mr. Perring's opinion as to the causes of the failures in some concrete buildings. In connection with the giving way of concrete I recall a case where a firm on two separate occasions invited a number of engineers to witness a test of a flat concrete beam. On each occasion the beam gave way when there had been placed on it only three fourths of the safe load that it was expected to carry. These failures were due to lack of cohesion in the center of the beam.

Frank E. Hahn.—The objection to using plaster blocks is, that when during construction heavy loads are placed on the wheel barrows and they are wheeled directly over the blocks while the concrete is being placed, there is a liability

of crushing the blocks. With the hollow terra cotta block, material can be wheeled directly over the block without causing any injury. When the concrete is placed in a very moist condition the sides of the plaster blocks next to the concrete filling become very soft and fragile. The terra cotta block, as ordinarily used in the construction of the combination reinforced concrete and hollow tile block according to the Kahn System, is of a hard burned clay, made very smooth but with corrugations on the sides about one-eighth of an inch in depth varying in width from one inch to two inches. This forms a bond for the concrete work, although the natural adhesion between the two materials would be sufficient to hold the block firmly in position.

E. M. Nichols.—Referring to the shearing value of concrete—I witnessed a test of two hangers embedded in some concrete arches which were five inches thick at the crown where the hangers were. One hanger pulled out at 11,000 pounds, tearing out a cone of the concrete. The other hanger gave way by the opening of the hook at 12,000 pounds without injuring the concrete. I have not any data respecting the size of hangers or depth of embedding. If the cone pulled out was four inches high and eight inches in diameter at base the rupture of the concrete took place at about 150 pounds stress per square inch.

Henry H. Quimby.—The paper seems to be somewhat meager in respect to the question of column design which it dismisses without giving the unit stresses employed or the method of compensating for unsymmetrical loads which it says were taken care of. The character and amount of reinforcement in both floors and columns, the construction of and method of waterproofing the roof, and analyses of the stresses set up by the cantilevering of the stairs and the balconies, would all be of interest, and it is to be hoped that the author will elaborate a little in closing the discussion.

The design of the long galleries or balconies is not pleasing to the eye because their appearance gives the impression that the support is inadequate. The feeling of the miscellaneous public observer is proper to be considered in designing the architectural features of a conspicuous structure. Brackets or, if the headroom were scant, cantilever beams formed under the balcony, would give an appearance of support and satisfy the eye without detracting from the grace or beauty of the building and might even give a little additional character to the architecture.

The difference between the parapets on the balconies—some being of brick and some of concrete—is noticeable and is not explained. The concrete parapets are lighter in appearance and probably in fact, for they need not be as thick as the brick walls.

Wm. Copeland Furber.—The history of reinforced concrete construction deserves the most careful study on the part of structural designers. Reinforced concrete has successfully met the charges of its critics and confounded many of the prophets who predicted nothing but failure for its portion. It is to-day recognized as one of the four methods of structural design, and these methods can be named in the probable order of their historic employment, viz., wood, masonry, iron, and lastly reinforced construction of iron and concrete. The evolution of the theoretical design of reinforced construction has been slow, largely because the engineering students were not quick to realize that the adhesion of concrete to metal could be used as a factor in determining the transfer of stresses from one

material to another. The value of rivets and bolts to transmit stresses could readily be calculated, because the facts were easily ascertained and easily proved, but the ability of the concrete in a beam to transmit the web stresses to a horizontal metal reinforcement or flange was not so readily comprehended. The definite certainty of riveted connections made it difficult to even think, let alone admit, that such a material as concrete would be trusted to transfer stresses to iron bars or rods, although it was quite easy to prove by trial that such a capacity existed. Theoretical objections to this proposition gave way upon trial to new conceptions based upon the newly discovered facts, and then the new theories appeared which embraced these facts.

With the advent of reinforced concrete, came the inevitable accompaniment of all things of a more or less mysterious nature: the quacks, who made many claims for the new material and whose real knowledge of the subject was purely empirical. The quack designers and the quack builders have done much to delay the final acceptance of the new combination, as a proper and legitimate form of structural design, and even now the unreasoning and unreasonable advocates of this new form of construction will not admit that this form of construction has any defects worthy of mention.

Reinforced concrete has, like all other good things, the defects of its virtues, and no intelligent designer can allow these defects to pass unnoticed, if he aims to keep his mind free from prejudice. Reinforced concrete deserves a high place as a method of construction, and with the growing scarcity of lumber its employment has become a practical necessity. It is also a step in the direction of the erection of permanent buildings with a resultant decrease in the fire hazard and a lessening of the spendthrift fire waste of which this country is the chief exponent. For this reason, if no other existed, the new construction can be hailed as a God-send.

There is, perhaps, no material used in construction in which the workmanship factor so largely enters. We may inspect iron, wood, bricks, stone, etc., and accept them or reject them as they meet or fail to meet our requirements, for they are finished units of construction, but while the separate component parts of the concrete are definite things, yet in their combined form they become a new chemical and mechanical substance which may be good or bad according to the intelligence and care used in mixing, placing, and protecting them until a proper setting has taken place.

There are several prevalent superstitions among the ordinary workers in concrete that seriously operate against the probability of good results being obtained unless the work is most carefully supervised. One of the superstitions is that cement possesses some magical property that enables a very small quantity to go a long way, or in other words, that it takes but a "little to leaven the lump" of sand and stone, and these same workmen think that they are doing their "boss" a good turn when they "skin" on the quantity of cement.

Another delusion is that "drying" and "setting" are coincident and that the first must occur before the second has happened. I suppose that reasoning from the setting of other materials, like paste, mucilage, glue, varnish, and other materials of like nature in which water or alcohol is the solvent, it is natural for them to suppose that cement must dry before it sets, and this belief causes no end of trouble, unless it is most carefully guarded against. I was called upon to investigate, last fall, two concrete structures which failed largely through the

belief on the part of the foreman of each job that the concrete should be allowed to dry out as fast as possible. Their efforts in this direction were aided by high winds and the cold weather which retarded the setting. In one instance, several buildings of a group and in another the floor system of a city hall collapsed. The contractor blamed the failure on the cement and threatened to sue the cement manufacturer for damages, but a little investigation showed that the failure in both instances was due to the belief on the part of the foreman on each job that rapid drying was not only desirable, but essential to the setting of the concrete. Had the foreman in each case known the fundamental chemical necessity for water during the setting, this failure would not have occurred.

Another great drawback to the use of concrete work is the uncertainty as to whether some careless, ignorant, or designing workman may not have spoiled the work at a critical point by improper methods or materials, and no subsequent inspection is going to detect this weakness until it is possibly too late to remedy it.

Carelessness, indifference, and irresponsibility seem to be the order of the day, and this is particularly so in the building trades. Where materials can be inspected after erection, as in brick work, stone work, iron work, etc., it is very hard to get even passably good results, but with a material that has to be taken on faith, like reinforced concrete, it requires a perpetual optimistic temperament to prevent undue anxiety from spoiling one's peace of mind.

Regarding the ignorance of the ordinary workers in concrete concerning the chemical value of water in the setting of cement, it should be remembered that cement is a chemical product and requires some brains to make proper use of it. When it was deposited in large masses, the chances of drying out, too rapid setting, and the disturbing of the mass due to vibration, were not great, but in reinforced concrete construction these dangers are ever threatening.

As a step in the education of the uninformed workers in cement, I would earnestly suggest to the manufacturers that they attach a tag to each bag or barrel of cement giving in a concise manner the essential facts regarding the use of water in the mixing and setting of cement. Thus, without any great effort, each man who handled a bag of cement would unconsciously perhaps become a missionary in spreading the knowledge of how cement should be used, and better work would follow and more cement would be used, and thus the manufacturer would reap an advantage for his altruistic labors in a material and pecuniary way.

The fireproofing of concrete structures is one that deserves as much study as the fireproofing of iron structures. The advocates of reinforced concrete construction do themselves no credit and do their material a great deal of harm by claiming that concrete is a fireproof material. The simplest tests which can be made by a school boy will prove that cement after setting cannot resist fire without detriment, and the point of absolute structural disintegration is determined solely by the length of time it is kept in contact with the fire. A few briquets, the kitchen range, and a bucket of water, will prove this in a most practical and satisfying way, and remove any lingering doubt one may have on the subject. Chemically, this conclusion can be justified by recalling that in the setting of cement from 10 to 25 per cent. is crystallized into the new mixture and remains there, not in the form of dampness—for the material can be perfectly dry—but as a chemical compound of the mass, and knowing this it can also be shown that this combination can be broken up and separated again by heat, which

brings the cement back to somewhat the original form it had before being mixed with water. All this being proven or admitted it is next in order to find a method to protect the concrete from reaching high temperatures, and our experience in fireproofing iron work will help us in this direction. Porous fire-clay blocks are useful as a slow conductor of heat and they will also withstand high temperatures without changing their chemical composition, and in addition their porous nature gives them the ability to resist sudden changes of temperature without fracture. By protecting the structural parts of the construction with this material it is possible to construct a building of great fire-resisting capacity at a cost considerably less than structural steel fireproofed with the same material.

The porous terra cotta manufacturers have provided a material which can be easily laid with the centering and which unites with the concrete, forming a monolithic structure with a protecting surface of porous fire-clay terra cotta.

The application of reinforced concrete to mill structures, which have heretofore been built of large sticks of lumber, helps wonderfully in the direction of better buildings. Large sticks of lumber are becoming very hard to obtain, and even when they can be obtained in good condition the subsequent checking of the wood seriously impairs their strength and capacity. Before the advent of reinforced concrete there was but one other way to obviate this and that was by the employment of structural iron work. In reinforced concrete we have a material which is particularly suited to commercial structures of all kinds, but in the employment of any composite material like reinforced concrete eternal vigilance is the price of safety.

H. G. Perring.—The concrete used was mixed in proportion of one part cement, three parts sand, and five parts broken stone.

The cement used was Vulcanite Portland, which under test showed final set at eight hours. The cement test throughout the course of construction showed very uniform results.

The sand used was the variety known as Jersey Gravel, a bank sand, yellow in color, free from loam, and having sharp grains.

The stone was trap rock, broken to pass through a three-quarter inch ring, dust screened out.

The reinforcing rods were plain, round, medium steel.

The plaster block is what is known to the trade as Keystone fireproof block. Its composition is in the main the purest calcined Nova Scotia gypsum, which is mixed with a small percentage of wood fiber, which serves as a binder and makes the block extremely tough. The blocks are moulded, the plaster being in an almost liquid state when poured. To regulate the set of the plaster certain chemicals are used, the exact nature of which is a trade secret. This set regulator or retarder, besides regulating the working quality of the material, so changes the qualities of the finished product that, unlike plaster of Paris, the block can be placed in direct contact with steel without causing rust or other disintegrating action.

Mr. Hahn's statement that there is an objection to the use of plaster block on the ground of breakability is not borne out by the facts. As stated in the paper, the breakage was about 1 per cent. The breakage of terra cotta used for filler block in the concrete floors of the Marlborough-Blenheim Hotel at Atlantic City exceeded that percentage. The author cannot bring to mind one instance dur-

ing the construction of the McIlvain apartment house in which the plaster blocks were broken by wheeling loaded barrows over them. Neither did the soaking which the blocks were given by the rain and by application of the hose affect their strength. The greater part of the breakage was caused by rough handling by the laborers in unloading from wagons and placing in the building.

The columns were designed as required by the Philadelphia Bureau of Building Inspection, using a unit safe compressive in the concrete of 500 feet per square inch, the steel reinforcement not being considered as taking any load. Where an unsymmetrical load was placed on a column the bending moment resulting from such load was calculated, and the steel called upon to act in the column the same as in a beam under flexure.

The roof construction was similar to that of the floors, the waterproofing being an ordinary tar and gravel roof.

The actual calculation of the stresses in the cantilever balcony and the cantilever construction around the stairs would probably not be of any particular interest. The method employed was to treat these as simple cantilevers, calculating the bending moment from the point of nearest support. The top of the slab was found to be in tension, and reinforcement of sufficient size to meet the tensile stresses was introduced and carried back about six feet into the beam construction of the interior.

Mr. Perrot's excellent addition to the author's paper is perhaps not properly a part of the discussion, but it is very welcome. It is, however, a matter of regret that a paper showing such thought should not be presented by itself.

The author heartily agrees with Mr. Furber that eternal vigilance is required in the execution of reinforced concrete work. Such work should never be entrusted to the care of an inexperienced contractor. It would, indeed, be preferable that the contractors on such work be engineers, understanding the necessity of care. Even then the inspection should be careful. The many recent deplorable failures of reinforced concrete could have been averted by inspection, which would insure a good quality of concrete and prevent the removal of forms before the concrete had set.

The proper placing of steel is a matter of importance, and has engaged the attention and thought of architects and engineers, resulting in such products as the unit girder frame and the girder frame of the General Fireproofing Company, which aim to eliminate the element of chance in the location of the steel. The most serious phase of the construction, however, is the concrete, and it is to be hoped that architects and engineers will strongly discourage the taking of reinforced concrete contracts by the cement pavement man.

Paper No. 1030.

FURTHER NOTE ON SUMMATION OF STRESSES IN CERTAIN STRUCTURES.[1]

JOHN C. TRAUTWINE, JR.

Read October 20, 1906.

On October 15, 1904, Mr. John Birkinbine presented, before this Club, an interesting paper on stave pipe, in the course of which he discussed formulas for the spacing of the bands.

Mr. Birkinbine's paper was printed in the Club "Proceedings," vol. xxii, No. 1, January, 1905, pages 12, etc.

In the course of the discussion of this paper, it was asked what effect the water-pressure would have upon the stresses already existing in the bands and staves and due to the initial tightening of the bands.

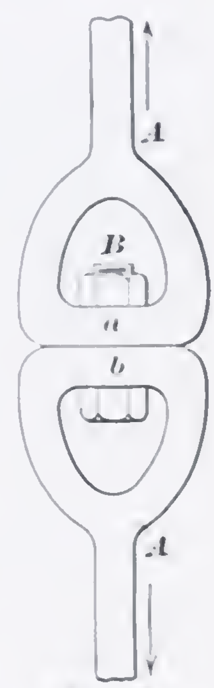


Fig. 1

It was suggested that this depended upon the capabilities of resistance (scientifically called the "elasticities") of the bands and of the staves, respectively.

As a result of this discussion, Mr. Carl Hering took up the matter, and, at the meeting of December 17, 1904, presented a "Note on the Summation of Stresses in Certain Structures," which was published in the same number of the "Proceedings" with Mr. Birkinbine's paper.

The writer believes Mr. Hering's presentation of the matter to be entirely correct; and, in the following, attempts merely an elaboration of the subject, leading to a more complete generalization.

It may be well here briefly to review Mr. Hering's argument.

Referring to Fig. 1, Mr. Hering says:

"Let *A* and *A*, Fig. 1, be two tension members held together by a bolt, *B*, which is put under permanent initial tension by having its nuts screwed down tightly. If, under these circumstances, a tension is applied to the member, *A*, *A*, as a whole, the question is: *is this tension added to that already existing in the bolt?* In other words, must

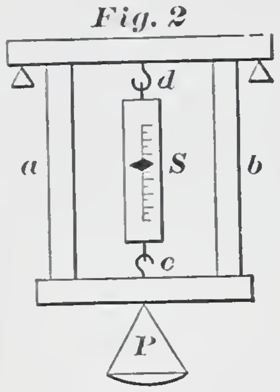
[1] See "Note on the Summation of Stresses in Certain Structures," by Carl Hering. Read December 17, 1904. "Proceedings Engineers' Club of Philadelphia," vol. xxii, No. 1, 1905, pages 74, etc.

the bolt be made strong enough to withstand the *sum* of the two strains? The bolts securing the cylinder head of a steam-engine, or the bands around a wooden stave pipe for high water-pressure, are fair illustrations of this problem occurring in practice."

"Some twenty-five years ago, when this same question arose, the writer made the following simple experiment: Referring to Fig. 2, *a*, *b*, *c*, and *d* are four blocks of wood held together by an ordinary spring scale, *S*, under tension, as shown. A scale pan, *P*, was attached to the lower block, and the whole system was suspended, as shown, by the two supports shown under the upper beam, one near each end.

"In this apparatus, the scale, *S*, represents the member under tension, and corresponds to the bolt, *B*, in Fig. 1. The members *a* and *b* are the members under compression, and correspond to the parts, *A* and *B*, in Fig. 1, which are compressed by the bolt. Weights placed in the scale pan, *P*, represent the additional and variable strains or loads applied externally to the system as a whole, as shown by the arrows in Fig. 1."

Fig. 2



The result of this experiment was that, in the case shown in Fig. 2, where *S* is easily extensible while *a* and *b* are practically rigid, "the externally applied strain was *not* added to the initial strain on the tension member, until the externally applied load equalled the initial tension in that member, which tension is necessarily equal to the combined compression in *a* and *b*."

"The effect of the weights in the scale pan was to diminish the compression on the members, *a* and *b*," until the added weights equalled the initial tension. When the added weights became *equal* to the initial tension, "the compressive strain on *a* and *b* was released entirely, and these members could then be withdrawn without changing anything in the system."

When the weights in the scale pan *exceeded* the initial stress, the stress on the tension member, *S*, increased accordingly, and remained constantly equal to the added weight, *P*.

Thus far we have been considering the special case where the tension member, *S*, is easily extensible, while the compression members, *a* and *b*, are practically rigid.

Mr. Hering, however, took up the investigation of the "elasticities" of the members, with the result shown by the diagrams in his Fig. 3.

Here let me digress for a moment to enter a protest against the slovenly manner in which terms in common use have been "strained" out of their common meanings by those who have had the framing of our scientific language.

The average man thinks of the *elephant* as *powerful* and of the *flea* as *energetic*. But scientific writers have fastened upon "energy" a meaning suggestive rather of the *elephant*, while "power," which they define as "time rate of work," is suggestive rather of the *flea*.

Again, not only the average man, but the trained engineer (as witness Mr. Birkinbine's and Mr. Hering's writings in the present connection) thinks of "strain" as synonymous with "stress." When we say that a man or a link is under "strain," we are thinking of the *stress* endured, not of the *elongation* or *compression* due to that stress. But the scientific writer, for some unexplained reason, has seen fit to decree that the word "strain" shall be used to indicate the linear *elongation* or *compression* due to stress.

This seems the more inexcusable, inasmuch as the convenient and definite word "stretch" was right at hand, and might as well have been used, compression being taken as negative stress.

According to the *popular* definition of "elasticity," that member is the most elastic which can return to its original condition *after the greatest distortion*. According to this view, india-rubber in tension is more elastic than cast-iron.

But writers on mechanics uniformly ascribe the higher modulus of elasticity to that member which, after a given stretch, exerts the greatest force in its efforts to return to its original condition, and this member is necessarily the one which exerts the greatest resistance to distortion. According to this view cast-iron is more elastic than india-rubber in tension.

Mr. Hering speaks of the *yielding* member as the *more* elastic one, and he is therefore rather in accord with the *popular* terminology, or the one first mentioned.

But, in order to conform to *scientific* practice, I assign the higher modulus of elasticity to the member exerting the greater resistance to distortion.

I thus reverse Mr. Hering's definition of elasticity.

In speaking of stresses, in this discussion, we mean *not unit* stresses, as in pounds *per square inch*, but *total* stresses, as in *pounds*, in the member under consideration; this total stress depending not merely

upon the *unit stress* of the *material* of which the member is made, but also and jointly upon the *cross-section area* of the *member*.

For instance, in Mr. Hering's Fig. 1, if the whole structure be supported at the upper end, and if a load of 1000 pounds be suspended from its lower end, then the stress, with which we are dealing, is 1000 *pounds*, and is the product of the unit stress by the cross-section area of the member.

In Mr. Hering's Fig. 3, as in the diagrams which I shall present, the *abscissas* represent the externally applied *load*, while the *ordinates* represent the corresponding total *stresses* in the members.

For convenience, the two scales are made equal. Thus, the same length, which, on the axis of abscissas, corresponds to an external load of one, two, or three pounds, corresponds, on the axis of ordinates, to a stress of one, two, or three pounds, respectively.

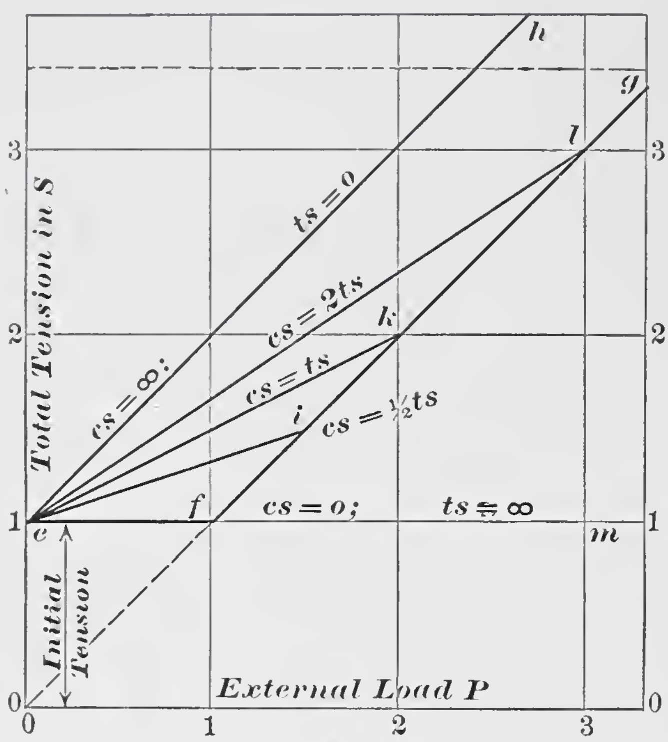


Fig. 3

In Mr. Hering's Fig. 3, the ordinate, 0 1, represents the "initial stress in the tension member."

This stress, being produced by, and dependent upon, the members in the structure, Fig. 2, themselves, is necessarily equal and opposite in the two members (considering *a* and *b* as acting jointly as a single member).

Thus, if the spring balance in Fig. 2 is made to show a *tension of* ten pounds, then the two posts, *a* and *b*, together, in the absence of external load, will sustain a *compressive stress* of ten pounds, or say five pounds each.

Evidently, by altering the tension in *S*, we can, at pleasure, increase or diminish the initial stresses (which, nevertheless, remain equal and opposite to each other, notwithstanding such alteration); but, for the sake of simplicity, we assume that this initial stress, once fixed in advance, is allowed to remain throughout undisturbed. It is represented throughout by the ordinate, 0 1.

The ordinates from the line, 1 1, to the inclined line, *eh*, and to the

broken lines, *elg, ekg, eig,* and *efg,* indicate the tensions, in *S*, Fig. 2, due to the *external* load alone; and, if added to the *initial* tension, *represented by the vertical ordinate,* 0 1, they give the *total* or *resultant* tensions in the spring, *S*.

The ordinates from the horizontal line, 0 0, are the *sums* of the constant ordinate, 0 1, representing the initial stress, and the variable ordinates from 1 1 to the inclined and broken lines, representing the stress due to the external load alone. Hence, the ordinates from 0 0 represent the *total* or *resultant* tensions in *S*, Fig. 1.

The differences, between these several inclined and broken lines, correspond to differences in stretchability of the two members.

Thus, in Fig. 2, where *S* is supposed to be quite stretchable, and where *a* and *b*, on the contrary, are supposed to be practically rigid, we have the conditions represented by the lowest broken line, *efg*.

In other words, in the case shown in Fig. 2, the stress in the tension member, *S*, remains constantly equal to the initial stress, 0 1, until the external load, *P*, becomes equal to this initial stress.

Thereafter, the stress in the tension member is equal to the external load.

I may here observe that, if either member is *absolutely* extensible or compressible, *i. e.*, if it can offer *no resistance whatever* to tension or compression, there can of course be no "initial tension."

Thus, in Fig. 2, if the two bars, *a* and *b*, yield indefinitely under the slightest pressure, then the spring balance, before the application of the external load, *P*, is constantly at zero; and, after the application of the external load, its reading will constantly be equal to that load, all as represented, in Fig. 3, by the straight line *ofg*, beginning at the lower left-hand corner of the diagram.

The broken line, *efg*, represents a case, Fig. 2, approximating this, but where the bars, *a* and *b*, have at least sufficient capacity for resistance to stand an initial stress of 1.

In Fig. 4, Mr. Hering has made the tension member, *S*, practically rigid, and the members, *a* and *b*, originally in compression, relatively compressible.

The case shown in Fig. 4 is represented approximately in Fig. 3 by the *upper* straight inclined line, *eh*, where *cs* (compressive stretchability) is practically infinite, and the tensile stretchability (*ts*) is practically zero.

Here, from the start, the tension member, *S*, Fig. 4, carries the entire load, *P*; and the corresponding line, *eh*, in the diagram, there-

fore inclines upward at an angle of 45°, the scales of abscissas and of ordinates having been made equal, as already remarked.

The remaining three lines represent cases where *both* members are regarded as capable of yielding to some extent.

Of these, the uppermost broken line, *elg,* represents a case where the compressive stretchability, **cs,** is twice the tensile stretchability, **ts,** and so on, as marked upon the lines.

Thus the middle line, *ekg,* represents the case where the compressive and tensile stretchabilities are equal, in other words, where the compression and tension members would stretch equally if each were subjected to the same load.

The next line, *cil,* represents the case where the compressive stretchability is half the tensile stretchability.

In each of these cases, the stress in the tension member increases *less rapidly than indicated by the line fg,* until the resultant stress in the tension member is equal to the external load, *P,* after which it remains equal to that load, as indicated by the line *fg.*

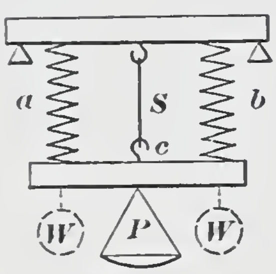


Fig. 4

This is explained by the fact that, before the compression members can be put out of commission, they must be relieved of the compression produced in them by the initial stress.

Thus, in the case indicated by the uppermost broken line, *elg,* where the compressive stretchability is *twice* the tensile stretchability, the initial stress has compressed the posts to such an extent that the external load must bring upon them a tensile stress, *ml,* equal twice the initial stress, 0 1, before they can cease absorbing part of the effect due to the external load.

For this reason, I have reversed, in my Fig. 3, Mr. Hering's statements of the conditions represented by these several lines.

In Mr. Hering's Fig. 3, the line, *elg,* is marked "*te*=0.5*ce,*" or, in my terms, "tensile stretchability=0.5 compressive stretchability." Now, by reversing this equation, and writing

"compressive stretchability=2 tensile stretchability,"

we see at once the reason for the coefficient, 2; namely, that the ordinate, *ml,* representing the effect of the external load in increasing the tension in the spring, is *double* the ordinate, 3*m,* or double the initial stress, 0 1.

Similarly, in the line, *eig,* which in my figure is marked $cs=\frac{1}{2}ts$, the ordinate, from 1 1, to the point, *i,* is *half* the ordinate, 0 1.

In Mr. Hering's Figs. 2 and 4, the added load necessarily brings *tension*, not only upon the central *tension* member, S, but also upon the two side, or *compression*, members, a and b; the difference being that, whereas this added tension of course *increases* the *tension* already existing in S, it *diminishes* the *compression* already existing in a and in b.

Respecting Mr. Hering's treatment of the subject, as outlined above, you will notice:

1. That he considers only the case where the external load brings *tension* upon the members;
2. That he does not discuss the stresses in the *compression* members;
3. That he does not consider the case where the compression member is so arranged as to be capable of sustaining *tensile* as well as *compressive* stress.

Finding the study an interesting one, and wishing particularly to understand more clearly its application to the case of stave pipe, I investigated it further, with the result shown in the following discussion, respecting which I remark:

1. That it considers those cases where the external load brings *compression* upon the members, as well as those in which it brings tension.
2. That it discusses the stresses in *all* the vertical members.
3. That it discusses the case where any member, if necessary, can sustain *reversal of stress* (making this indeed the general case).
4. That it shows more clearly the application of the principles involved in the case of *stave pipe*.

In Figs. 5 (*a*), (*b*), (*c*), and (*d*), it will conduce to clearness if we conceive of *only two* vertical members, P and N; the *outer* one, in each case, being a *cylinder*, as shown in the plans above the vertical sections. In these vertical sections, the wall of each cylinder, of course, shows on each side of the figure.

In Fig. 5 (*d*) you will recognize Mr. Hering's Fig. 2, where the external weight, W, applied to the lower beam, brings tension upon the two vertical members, P and N, and where the extensible central member is initially under *tensile* stress.

In Mr. Hering's Fig. 4, also, W brings tension upon both members, and the central member is initially under tension; but the outer or compression members, a and b, are compressible, whereas in Fig. 2 they are practically rigid.

In each figure, as in Mr. Hering's Figs. 2 and 4, the external load, W, is supposed to be applied symmetrically, and the beams are sup-

posed to be rigid, so that both the internal stresses and those due to the external load are uniformly distributed over the cross-section of the outer member.

Pictorial exigency has rendered it advisable to represent the tension members by means of spring balances, and by means of rods secured by hooks; and, in Figs. (*b*) and (*c*), to represent the compression member by a coil spring.

But, for the purposes of this discussion, these must be supposed replaced by *prismatic* members, *i. e.*, by members of uniform cross-section throughout the distance between the two beams, and, where necessary, they must be supposed attached to the beams by some method not affecting their lengths.

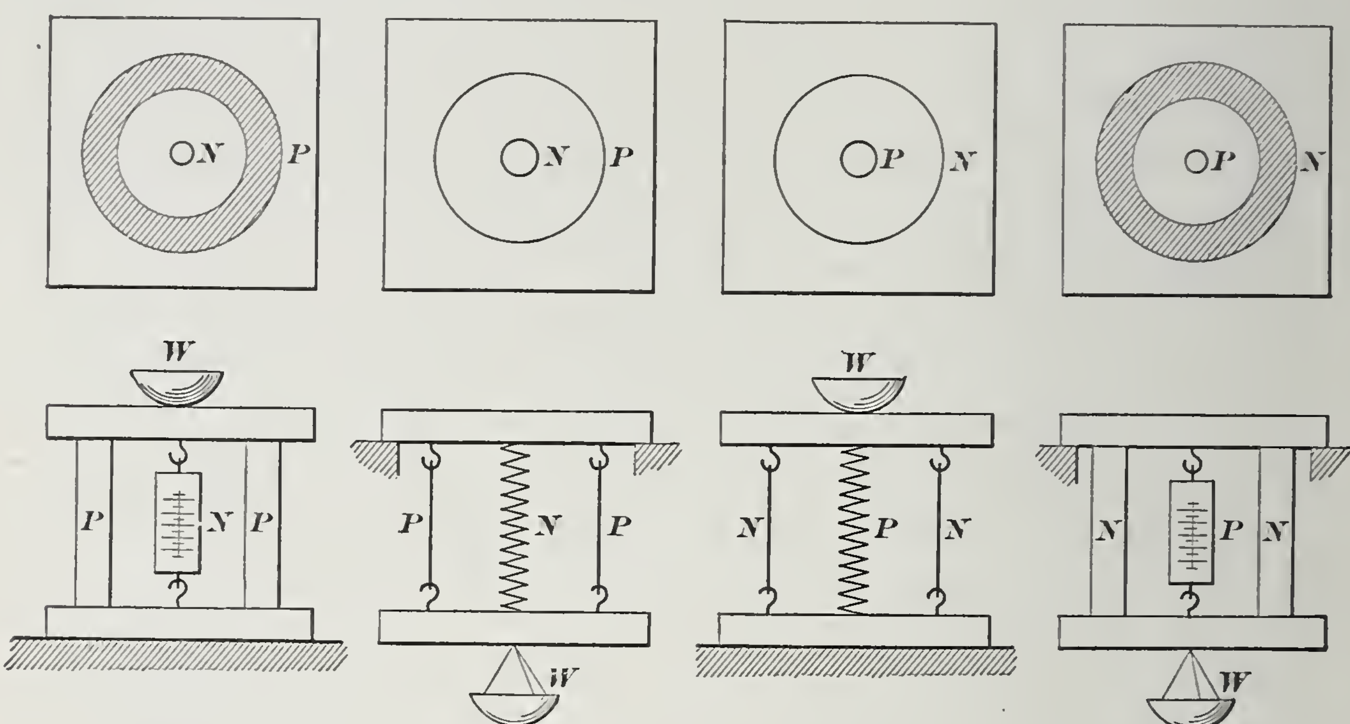


Fig. 5

As before, the internal stresses are necessarily equal and opposite, and, for the sake of simplicity, we assume that they remain constant throughout.

As already remarked, the effect of the external load, W, in any given case, is to produce either *tension* in *both* members or *compression* in *both* members; but, owing to the opposite signs of the internal stresses, the external load *adds* to *one* of these, and *subtracts* from the *other*.

That member, as the cylinder, P, in Fig. (*a*), and the spring balance, P, in Fig. (*d*), in which the external load *adds to* the internal stress, is in each case called P; while the *other* member, in which the external load *subtracts from* the internal stress, is called N.

In all cases, the action of the external load, W, on P and on N is considered as positive, whether it be tensile or compressive.

Let me repeat that, in speaking of stresses, we deal, *not* with *unit* stresses, but with *total* stresses.

The four figures, (a), (b), (c), and (d), represent cases differing only in the manner of application of the load, and in the arrangement of the two vertical members.

Thus, in Fig. (a), the structure is supported below, while the external weight, W, is applied above. Here the effect of the external load, W, brings *compression* upon *both* members, *increasing* the existing *compression* in the cylinder, P, and *diminishing* the existing *tension* in the spring balance, N.

In Fig. (d), on the contrary, the structure is suspended by means of the upper beam, and the external weight, W, is applied below, bringing tension upon both members, and thus increasing the existing tension in the spring balance, P, and diminishing the existing compression in the cylinder, N.

The problem involves, merely:

1. The *distribution of the external load*, W, between the two members, P and N.

2. The *resultant* stresses, due to the *superimposing* of the "*W stresses*" upon the *internal* stress already existing.

Let

E_p = the elastic modulus of the material of P;
E_n = the elastic modulus of the material of N;
F_p = the cross-section area of P;
F_n = the cross-section area of N;
i = the internal stress in P;
$-i$ = the internal stress in N;
p_w = the effect of W upon the stress in P;
n_w = the effect of W upon the stress in N;
$c* = \frac{p_w}{n_w}$ = the ratio of the resistances, offered by P and by N, respectively, to any given load, W;
$p = p_w + i$ = the resultant stress in P;
$n = n_w - i$ = the resultant stress in N.

I need scarcely remark that *the elastic modulus* of any material under stress is the ratio of the *unit stress*, as in pounds per square

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* In the figures both C and c refer to this ratio.

inch, acting upon a piece of that material, to the *unit stretch* (as in fractions of a foot per foot), produced by said unit stress.

The stresses, p_w and n_w, which are defined as "the effect of W upon the stress in P (or in N, as the case may be)," may also be defined as "that portion of W sustained by P" (or by N, as the case may be).

As stated in the foregoing list of symbols, c is the ratio, $\frac{p_w}{n_w}$, between the resistances offered by P and by N, respectively, to any given load, W.

In other words, it is the ratio in which W is distributed between the two members, P and N; because, according to Hooke's law—"ut tensio sic vis"—the resisting force, exerted by any given member, is proportional to the distance through which that member is elongated or compressed.

In other words again, c is the ratio between the (total) forces required to produce a given stretch in P and in N, respectively.

The importance of this ratio, c, and, indeed, of this entire discussion, has recently been greatly augmented by the extensive use of reinforced concrete; where the stresses, due to any given load, are distributed, between the concrete and the reinforcement, in the ratio, c, of the resistances which they can respectively offer to forces tending to change their dimensions.

The *resultant* stresses, p and n, in P and N, respectively, are necessarily the *algebraic sums* obtained by adding the stresses p_w and n_w, *due to W*, to the *internal* stress, i or $-i$.

Since p_w and n_w are merely component parts of W, we have

$$W = p_w + n_w$$

whence, also,

$$\begin{aligned} W &= p_w + i + n_w - i \\ &= p \pm n \end{aligned}$$

$+$ or $-$ depending upon whether the effect, n_w, of the external load, upon the member, N, is greater or less than the internal stress, i.

Fig. 6 shows graphically the distribution of the external load between the two members, P and N, in the selected case where $c = 2$, *i. e.*, in the case where the member, P, is capable of exerting *twice* the resistance which the member, N, can exert.

You will remember that P is the member in which the external load, W, *adds* to the internal stress, i; while N is the member in which the external load, W, tends to *reverse* the internal stress, $-i$.

Now, according to a well-known law, the resistance, offered by P, in any given case, is

$$p_w = E_p F_p \frac{l}{L}$$

where

$E_p =$ the elastic modulus of the material in P;
$F_p =$ the cross-section area of P;
$L =$ the original length of P;
$l =$ the elongation produced in P.

and n_w, found in the same way, gives us the corresponding resistance exerted by N. Thus:

$$n_w = E_n F_n \frac{l}{L}$$

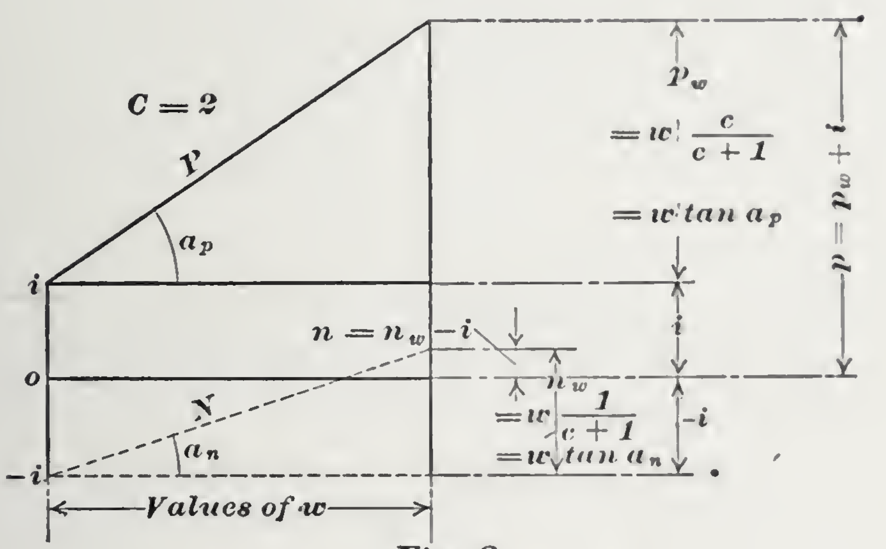


Fig. 6

Now, in the four cases shown in Fig. 5, as in Mr. Hering's Figs. 2 and 4, the original length, L, and the elongation, l, are necessarily equal, by construction, for both members.

Hence, $\frac{l}{L}$ cancels out; and we have

$$c = \frac{p_w}{n_w} = \frac{E_p F_p}{E_n F_n}$$

It will be noticed that this is the case ordinarily with reinforced concrete; for the reinforcing material, forming, as it does, an integral part of the whole, and being presumably prevented from slipping, necessarily has the same original length, and the same change of length, as has the concrete itself.

Now

$$p_w = W \frac{p_w}{W}$$

and, since $W = p_w + n_w$, we have

$$p_w = W \frac{p_w}{p_w + n_w}$$

Now, dividing numerator and denominator by n_w, we have

$$p_w = W \frac{c}{c+1}$$

By a similar operation, we obtain

$$n_w = W \frac{1}{c+1}$$

But, as shown in the diagram,

$$p_w = W \tan a_p$$
$$n_w = W \tan a_n$$

hence

$$\tan a_p = \frac{c}{c+1}$$

$$\tan a_n = \frac{1}{c+1}$$

Again it will be remembered that, in this discussion, the stresses due to the external load are invariably regarded as positive, whether they are tensile or compressive.

The positive stresses, p_w, caused by the external load, W, in the member, P, are simply added to the positive internal stress, represented in the diagram by the ordinate, $0\ i$.

In the other member, N, however, the internal stress $0—i$ is *negative,* and therefore of opposite character to the positive stress, n_w, brought upon N by the external load, W.

In other words, the external load, W, *adds to* the resultant stress in P, and *subtracts from* the resultant stress in N, and we have

$$p = p_w + i = W \tan a_p + i$$
$$n = n_w - i = W \tan a_n - i$$

Let me remark once more that the *internal* stresses, *as such,* are supposed to remain constant throughout, and that they are *independent* of the stresses due to the external load, and vice versa. But the *resultant* stresses depend upon *both* of these, and are equal to their algebraic sums.

The point, where the stress, n_w, in N, due to the external load,

becomes equal to the internal stress, $-i$, in N; in other words, where the diagram for N crosses the zero line of stress, I call the "critical point." Before the critical point is reached, the resultant stress, n, $=n_w-i$, in N, is negative; at the critical point it is $=0$; beyond the critical point it is positive.

This last applies, of course, only to the case where the member, N, is supposed to be capable of reversal of stress. Otherwise, beyond the critical point, the stress in N remains $=0$.

In Fig. 6, for illustration, we selected a case where $c=2$, that is, where P exerts *twice* the resistance exerted by N.

Fig. 7 shows the stresses, in P and in N, for the four cases:

$$c=\infty \qquad c=2 \qquad c=\tfrac{1}{2} \qquad c=0$$

As already remarked, where either member is perfectly yielding, there can be no internal stress, and we have simply the two heavy lines marked "special," radiating from the zero point, 0.

The other lines are based upon the supposition that the members are capaple of sustaining at least the internal stresses represented by the ordinates, $0+i$ or $0-i$.

The diagram, for each of the four cases, is constructed upon the principles of Fig. 6; the tangent of the angle, in each case, being determined by the ratio, c, between p_w and n_w, as in the following table:

c $=\frac{p_w}{n_w}$	p_w $=W\frac{c}{c+1}$	n_w $=W\frac{1}{c+1}$
∞	W	0
4	$\frac{4}{5}W$	$\frac{1}{5}W$
2	$\frac{2}{3}W$	$\frac{1}{3}W$
1	$\frac{1}{2}W$	$\frac{1}{2}W$
$\frac{1}{2}$	$\frac{1}{3}W$	$\frac{2}{3}W$
$\frac{1}{4}$	$\frac{1}{5}W$	$\frac{4}{5}W$
0	0	W

By considering the fractional coefficients in the table, and comparing them with the diagram, it will be seen that each of them corresponds with the formula at the head of its column, the coefficients for p_w being $=\frac{c}{c+1}$, while those for n_w are each $=\frac{1}{c+1}$.

In the general case, where N is supposed *capable of reversal* of stress, the solid lines, P, representing the stresses in P, and the dotted lines, N, representing the stresses in N, run through as straight lines from their respective origins, i and $-i$, to the end of the diagram. But when N is supposed *incapable of reversal* of stress, they extend, in their original directions, only to their intersections with the heavy lines marked "special," as in Mr. Hering's Fig. 3.

In many cases, as in those of tanks and of stave pipes, that member, N, in which the external load subtracts from the internal stress, is incapable of reversal of stress; and usually, in such cases, it is not permissible to allow the stress in N to reach the "critical point," where the stress becomes zero and reverses. In such cases, we have to do only with those portions of the diagram to the *left* of the *upper* special line and *below* the *lower* special line.

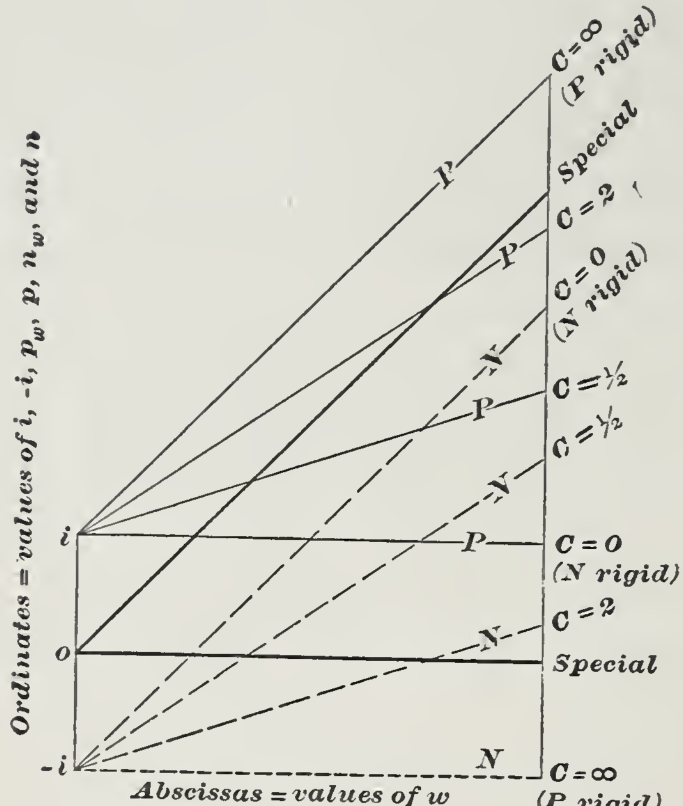


Fig. 7

At first sight, it may seem erroneous to speak of the water-pressure, in a stave pipe, as "external"; but it must be remembered that this pressure, while of course *internal* to the *pipe*, is *external* to the *system of bands and staves* which we have under consideration, and between which our "internal" stresses are exerted.

In Fig. 8 we have a case somewhat less simple than those shown in Figs. 5, the difference being that, in Fig. 8, the external load, W, instead of being applied immediately to one of the main beams, is applied to a third beam, which is supported partly by the upper coil springs, N, and partly by the lower coil springs, P'.

The demonstration, thus far given, and illustrated by Figs. 5, depends upon the fact that, in those figures, both members had the same original lengths, L, and that both underwent the same lengthening or shortening, l; so that $\frac{l}{L}$ was the same in both members, and therefore cancelled out.

In Fig. 8, if the lower spring, P', were rigid, the elongation, l_n, of the upper springs, N, would be equal to the elongation of the cylinder, P; but, if the lower springs, P', are compressed by the weight, W, then the elongation, l_n, of the upper springs, N, is equal to the *sum* of the elongation of P and the compression of P'. Or

$$l_n = l_p + l_{p'}$$

and

$$c = \frac{p_w}{n_w} = \frac{E_p F_p \dfrac{l_p}{L_p}}{E_n F_n \dfrac{l_n}{L_n}} = \frac{E_p F_p}{E_n F_n} \cdot \frac{l_p}{l_p + l_{p'}} \cdot \frac{L_n}{L_p}$$

I regard Fig. 8 as illustrating the case of stave pipe, shown, in very exaggerated manner, in Fig. 9, which illustrates a quadrant of a stave pipe with very small bore (radius $= R$), and of proportionally enormous thickness ($R_b - R$). In Fig. 9, the solid lines, B and S, represent the center-lines of band and of stave circle respectively, when the water-pressure, P, is zero (radii $= R_b$ and S_b, respectively), while the dotted lines, B' and S', show the positions of the same center-lines after the pipe has been distended by a water-pressure, P. Thus x represents the displacement of the band circle, and y that of the stave circle, by the water-pressure.

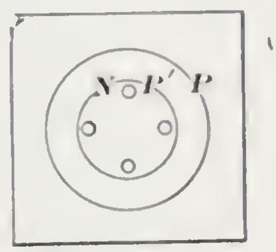
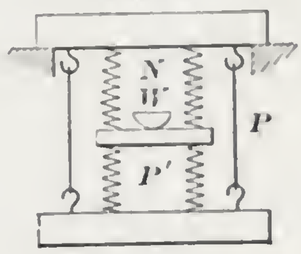


Fig. 8



In a stave pipe, Fig. 9, the "external" load, W, of Fig. 8, is the water-pressure, P, which, by pushing the staves farther out from the axis of the pipe, brings them into a circle of greater circumference, and thus reduces the circumferential or lateral pressure upon them.

The *staves*, acting *laterally*, therefore, correspond to the *upper coil springs*, N, of Fig. 8, which are internally in compression, but which are partially *relieved* of that compression by the tension due to the load, W. The *bands*, Fig. 9, internally in tension, and having their tension *increased* by the water-pressure, correspond to the *tension cylinder*, P, of Fig. 8; while the lower coil spring, P', Fig. 8, internally in compression, and having that compression *increased* by the external load, W, represents the *staves*, acting *radially*, and their surface of contact with the bands; for the same water-pressure, P, which *relieves*

the *lateral* pressure in the staves, *increases* their *radial* pressure against the bands.

Owing to the radial compression of the staves, under the water-pressure, and to the indentation of their outer surface by the bands (see Fig. 11), the center-line, S, of the stave circle, moves outward farther than does the center-line, B, of the band. Or

$$y = x + \text{compression and indentation of staves;}$$

and, as in Fig. 8,

$$l_n = l_p + l_{p'} = \text{elongation of stave circle.}$$

In Fig. 9

$$L_p = \frac{\pi R_b}{2} = \text{length of quadrant of } \textit{band} \text{ when } P = 0;$$

$$L_n = \frac{\pi R_s}{2} = \text{length of quadrant of } \textit{stave circle} \text{ when } P = 0;$$

$$l_p = \frac{\pi x}{2} = \text{elongation of } \textit{band} \text{ quadrant under water-pressure, } P;$$

$$l_n = \frac{\pi y}{2} = \text{elongation of } \textit{stave} \text{ quadrant under water-pressure, } P.$$

Then

$$\frac{l_p}{L_p} = \frac{\pi x}{2} \cdot \frac{2}{\pi R_b} = \frac{x}{R_b}; \qquad \frac{l_n}{L_n} = \frac{\pi y}{2} \cdot \frac{2}{\pi R_s} = \frac{y}{R_s}$$

and (see Eq., p. 137)

$$c = \frac{p_w}{n_w} = \frac{E_p F_p}{E_n F_n} \cdot \frac{x}{y} \cdot \frac{R_s}{R_b}$$

In stave-pipe practice, $\frac{R_s}{R_b}$ usually ranges between 0.93, in small pipes, and 0.96, in large pipes. It may, therefore, often be taken as unity, especially in large pipes. We then have

$$c = \frac{p_w}{n_w} = \frac{E_p F_p}{E_n F_n} \cdot \frac{x}{y}$$

Hence, if E_p, F_p, E_n, and F_n remained constant, we should expect c to diminish slightly, under continued pressure, as the staves were pushed further out from the center (the bands indenting them), thus perceptibly increasing the value of y but not that of x.

But Fig. 10 indicates that the value of c increases, under water-pressure, rapidly at first, and afterward more slowly; and it seems reason-

able to attribute this to a diminution of the elastic modulus, E_n, of the staves, due to their absorption of water. It may be due also to the fact that, after the introduction of water-pressure, the staves and the bands, owing to the friction between them, require some time to adjust their relations.

Fig. 10 shows the results of experiments made by Mr. D. C. Henny, and recorded in "Transactions American Society of Civil Engineers," vol. xli, June, 1899, page 70.

In Fig. 10 we neglect the internal and the resultant stresses, and consider only those stresses due to the external load. Hence in that figure our zero line, 0 0, of ordinates, is the line representing whatever internal stress there happens to be.

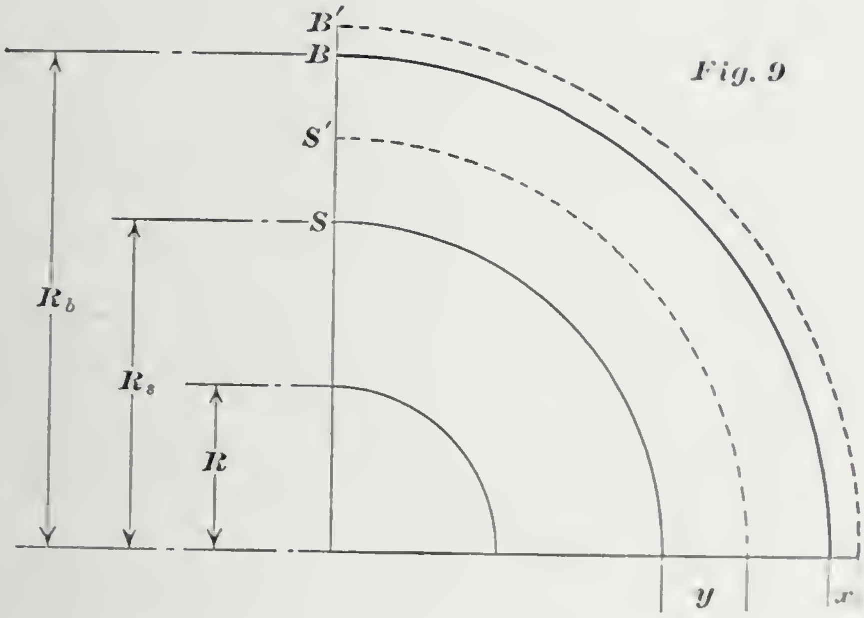


Fig. 9

The experiments comprise two sets: one of them with band spacing, *d*, = 5 inches, and the other with band spacing, *d*, = 10 inches. The water-pressures (observed) are plotted as abscissas, and the band and stave stresses and the values of *c* as ordinates. The first set (pressures from 0 to 20 pounds per square inch) occupied 35 days; the second set (20 to 60 pounds) 9 days.

The water-pressures and the band stresses were measured, and the stave stresses were taken as the differences between the water-pressures and the band stresses.

The dash-and-dot lines represent the increase, B_P, in the band stresses, *B*, due to the water-pressure, *P*; the dotted lines represent

the corresponding decrease, S_P, in stave stresses, S; and the solid line represents values of their ratio,

$$c=\frac{B_P}{S_P}$$

Here, as in Figs. 6 and 7, the reduction, S_P, in the staves, is plotted *upward*, as is the increase of tension, B_P, in the bands; and this is as it should be, because both of these effects are really increases in tension, although, in the staves, this increase appears as a diminution in compression.

It will be noticed that, in the left-hand part of the diagram, the increase, S_P, of the tension, S, in the staves, due to external load, is

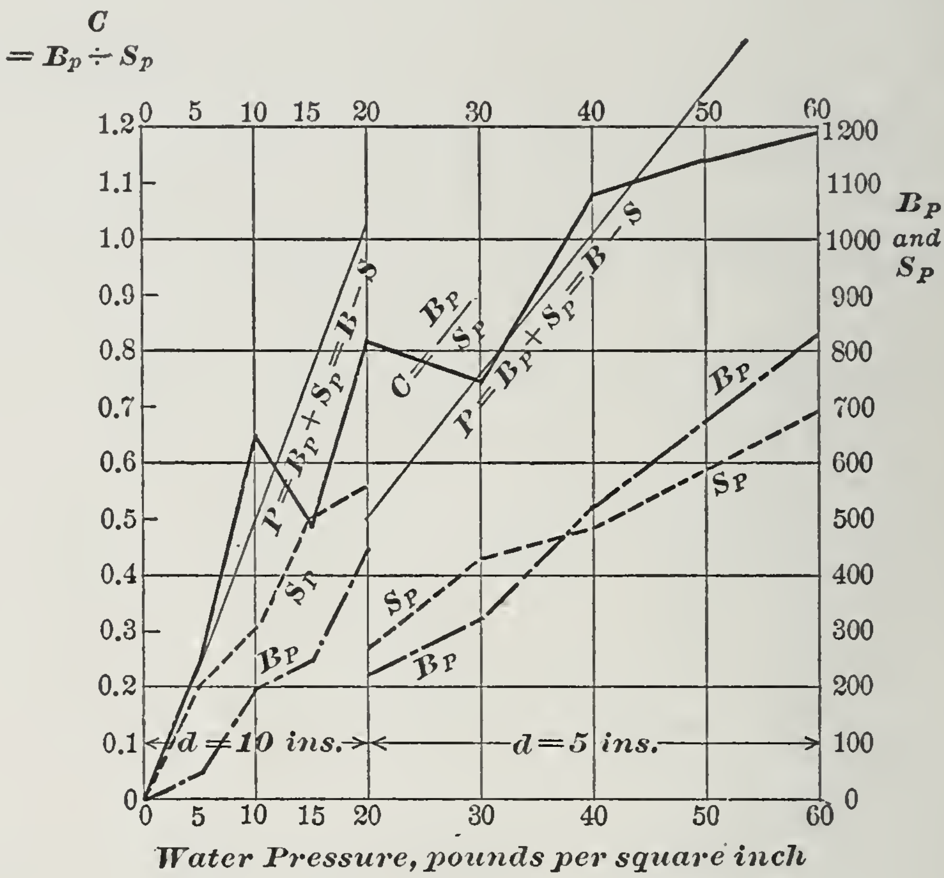


Fig. 10

greater than the increase, B_P, of the tension, B, in the bands, and hence, in this part of the diagram, the ratio, $c=\frac{B_P}{S_P}$, is less than unity.

A little beyond the center of the diagram, the two lines cross. At this point, therefore, the value of their ratio, c, is unity. Beyond this point, B_P slightly exceeds S_P, and the value of their ratio, c, is therefore a little greater than unity.

It will be noticed that the values of c vary quite irregularly from 0.248, for a unit water-pressure of 5 pounds per square inch, to 1.19, for a unit water-pressure of 60 pounds per square inch.

In Fig. 10 the straight inclined lines, P, represent the total water-pressures exerted upon a quadrant of the pipe, over a length of pipe equal to the band spacing, d.

The ordinates to the lines, P, are the sums of the ordinates to the lines, B_P and S_P. They therefore also represent the sums of the band tensions, B, and stave compressions, S, under water-pressure.

Hence, the values of P increase twice as rapidly with the unit water-pressure, when the band spacing, d, is ten inches, as they do when d equals five inches.

Fortunately for the engineer, it is found practicable to furnish satisfactory working formulas for the two principal problems, without recourse to the value of c.

The market sizes, in which the staves are furnished, usually provide sufficient strength for them; and we are concerned principally with the two questions of the *size* and the *spacing* of the *bands*.

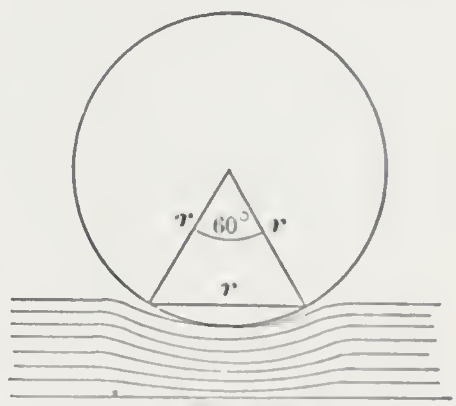


Fig. 11

In Fig. 12 we see the lower half of a piece of stave pipe showing three bands. Consider that portion of the piece embraced between two sections, taken midway between the central band and those on each side of it, respectively. Let this central portion be cut away from the rest of the piece, let it be cut again in the central plane, CX, and thus divided into two quadrants, and consider only the nearer one of these two quadrants.

Let

R = the inner radius of the pipe;
d = the band spacing = the length of the section under consideration;
t = the stave-thickness;
p = the unit water-pressure;
s = the unit stave-pressure;
a = the cross-section area of the band.

Acting vertically upon the quadrant in question, we have, in equilibrium, three forces, viz.,

(1) $P = p.Rd$ = the water-pressure, downward;
(2) $S = s.td$ = the compression between staves, downward;
(3) $B = b.a$ = the tension in the band, upward.

Acting horizontally upon the same quadrant, we have three forces, respectively equal and similar to these; and the moments of these six forces, taken about any axis, as the axis, AX, of the pipe, will also be found in equilibrium.

In practice, Fig. 11, it is found desirable that the band should penetrate the staves to a depth equal to about one-eighth of its diameter. When this is the case, we have, approximately, an equilateral triangle formed between the two radii of the band shown and the chord of the arc of contact between band and staves. In other words, chord of arc of surface of contact = radius, r, of band.

Let k = the radial pressure, exerted by the staves against the band (and, of course, by the band against the staves), in pounds per square inch. Then $k' = kr$ = the same pressure in pounds per linear inch of band; and (Fig. 12)

$$K = k' \ (R+t) = kr(R+t)$$

= the sum of the components of the radial pressures, acting, in a direction parallel to B and S, upon the portion of the pipe covered by the surface, $Rd + td = (R+t)d$.

But this sum, K, is necessarily equal to the band tension, B. Hence

$$r = \frac{B}{k(R+t)} = \frac{15{,}000\pi r^2}{k(R+t)}$$

Dividing each side of the equation by r^2 we have

$$r = \frac{k(R+t)}{15{,}000\pi}$$

In practice, k is limited by the safe crushing strength of the wood under the bands; and this is usually taken as 650 pounds per square inch. Hence

$$r = \frac{650(R+t)}{15{,}000\pi}$$

We now have to consider the *spacing* of the bands, Fig. 12. In the general case of summation of stresses, we found that the external load, W, was equal to the sum of its effects, p_w and n_w, upon the stresses in the two members, P and N, respectively.

Similarly, the total water-pressure, P, is equal to the sum of its effects, B_P and S_P, upon the band and the staves respectively.

Adding and subtracting B_0, the value of the internal band stress, or of the band stress when $P=0$, we have

$$\begin{aligned} P &= B_P + B_o + S_P - B_o \\ &= B_P + B_o + S_P - S_o \end{aligned}$$

where S_o = the stave stress when $P=0$. Now, since S_P must be kept $<S_o$ (in order to prevent leaking), we have S = compression. or minus, and

$$P = B - S$$

Hence,

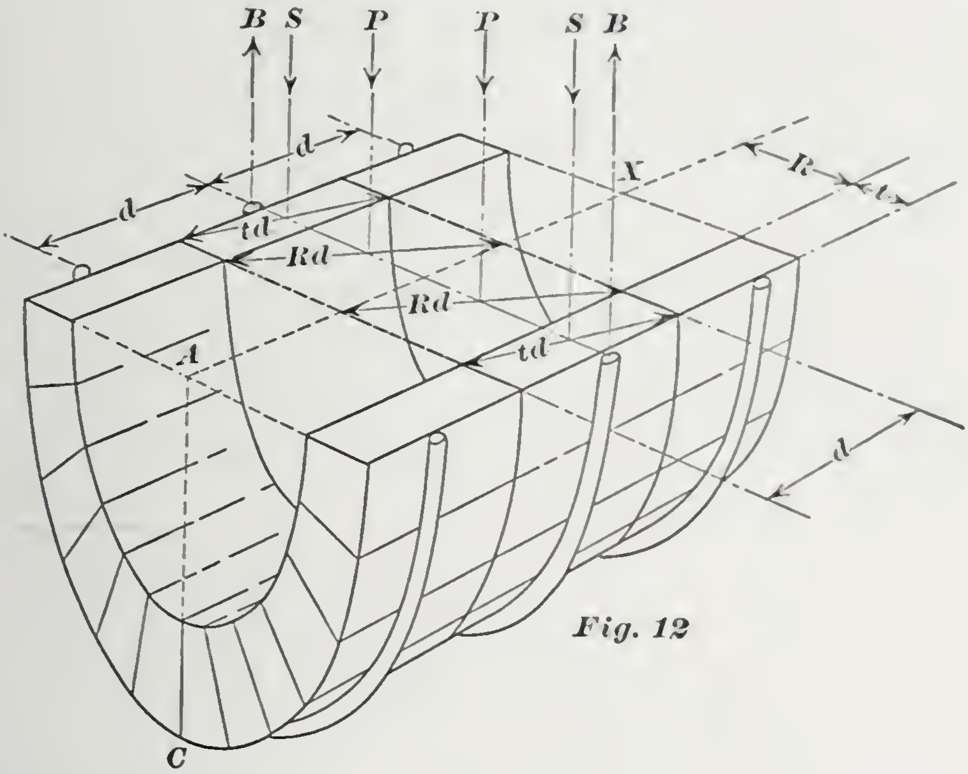


Fig. 12

$$\begin{aligned} B &= P + S \\ &= p \,.\, Rd + s \,.\, td \\ &= d(pR + st) \end{aligned}$$

and

$$d = \frac{B}{pR+st} = \frac{K}{pR+st} = \frac{kr(R+t)}{pR+st}$$

As already stated, 650 pounds per square inch is usually taken as the value of k.

For the safe unit compressive stress, s, in the staves, 100 pounds *per square inch,* is usually taken.

Hence we have, *in inches,*

$$d = \frac{650r(R+t)}{pR+100t}$$

and, for the number, N, of bands in 100 feet or 1200 inches,

$$N = \frac{1200}{d} = \frac{1200(pR + 100t)}{650r(R+t)}$$

$$N = \frac{2(pR + 100t)}{r(R+t)}$$

Mr. Henny ("Trans. Am. Soc. C. E.," vol. xli, p. 71, June, 1899) believes that, with usual band spacing and stave thickness, tightness is generally assured when the average unit pressure, s, between staves, is not less than $\frac{3}{2}p$. Adopting this value, we have:—

$$d = \frac{650\, r\, (R+t)}{pR + \frac{3}{2}pt} = \frac{650\, r\, (R+t)}{p(R+\frac{3}{2}t)}$$

and

$$N = \frac{1200}{d} = \frac{1200\, p(R+\frac{3}{2}t)}{650\, r\, (R+t)}$$

or, approximately,

$$N = \frac{2p(R+\frac{3}{2}t)}{r(R+t)}$$

Frequently the stave pressure, s, is neglected in arriving at the band spacing. The formulas then become

$$d = \frac{B}{pR}$$

$$N = \frac{1200}{d} = \frac{1200pR}{B}$$

or, if $D = 2R =$ diameter of pipe, we have

$$N = \frac{600pD}{B} = \frac{600pD}{K} = \frac{600pD}{kr(R+t)} = \frac{600pD}{650r(R+t)}$$

or, approximately,

$$N = \frac{pD}{r(R+t)}$$

The danger, involved in neglecting the stave stress, increases as the stave-thickness increases relatively to the diameter of the pipe.

The penetration of the staves by the band, Fig. 11, involves not merely the pressing of the fibers closer together, parallel to themselves, as in the lateral compression between the edges of adjacent staves, but also the bending and lengthening of some of the fibers, and their being forced to slide one over the other. In other words, the band penetrates the staves by a punching action, the wood being in double

shear. It therefore develops here a much higher unit resistance than in mere sidewise compression.

On page 14 of the Club "Proceedings," vol. xxii, no. 1, Mr. Birkinbine gives formulas for band spacing, expressed in the number, N, of bands in 100 feet length of pipe. I notice three typographical errors in the presentation of these formulas.

In the first formula, the pressure, P, due to one foot of head, should be stated as 0.44 pounds *per square inch.*

In the second formula, the pressure, P, should be stated in pounds per square *inch, not* per square *foot.*

In the second formula, S should be stated as the safe working "strain" in *pounds, not* in pounds *per square inch.*

I notice, also, that 600 in the first formula is equivalent to $\frac{1200}{2}$ in the second formula; that D in the first formula is $= D$ in the second; that PH in the first is $= P$ in the second; and, finally, that $\frac{F}{AB}$, in the first, is $= S$ in the second.

In other words, Mr. Birkinbine's two formulas are identical with each other, and with the simplified and less safe formula, given above,

$$N = \frac{1200\,pR}{B}$$

in which the stave stress is neglected.

DISCUSSION.

Carl Hering.—I am pleased to see that Mr. Trautwine has found the matter contained in my brief note to be of sufficient interest to elaborate, as he has done. The subject-matter seems to me to warrant it, and Mr. Trautwine's able and extended development of it will no doubt be of great interest and value to those confronted with this greatly misunderstood and neglected problem. I am pleased that some one has been sufficiently interested to develop the subject much more than I did.

I must, however, take exception to his intimation that the sense in which I used the term "elasticity" is unscientific. This term is unfortunately used in two diametrically opposite senses, both of which are authoritative and both of which "conform to scientific practice." I cannot agree that one is scientific and that the other is not. In scientific writings a gas, for instance, is often described as being "highly elastic" or even "perfectly elastic," while, according to Mr. Trautwine's adopted scientific definition, a gas is so very poorly elastic that it might even be called inelastic, because its modulus of elasticity is so extremely low. According to his use of the term, lead would be far more elastic than gas, which seems rather unacceptable. In the sense in which I used the term elasticity, a gas is more elastic than lead.

Mr. Trautwine's use of this much abused term is based on the assumption

that the modulus of elasticity, as at present used, is a *measure of the elasticity;* and that, therefore, if the modulus is high, the elasticity is great, and vice versâ. This modulus, however, is really a measure of the power of *opposing distortion* or resisting it, and hence is the reciprocal of the elasticity in the more usual sense. The reciprocal of this quality is a more convenient figure for engineers to use, which probably explains why it came into use, in preference to the direct ratio. To say that the elasticity of a body is measured by its modulus, seems to me to be like saying that (as is common practice) the *efficiency* of an incandescent electric lamp is measured in watts per candle, which in point of fact really measures the *inefficiency* or the reciprocal of the true efficiency.

In authoritative books it will be found that the definition of the term elasticity, like that of stress and strain, is not a single definite one, but that different and even diametrically opposite definitions are authoritative. Hence, no one has a right to say that one definition is right and the other is wrong, nor that one is scientific and the other is not.

His terms "compressive stretchability" or "negative stretchability" will probably not meet with general acceptance, for obvious reasons.

In my original note I called special attention to the fact that the results are represented by a *broken* line, and that the bending point of this line often represents an important point in practice, namely, the point at which a wooden stave pipe, a cylinder head, etc., will begin to leak. I called attention to the danger of representing these results algebraically by a right line equation, as that must of necessity be wrong beyond this bending point, except for the rare case in which a member can stand a reversal of the strains. Mr. Trautwine, in giving right line equations, has assumed the latter as the general case and mine as a special case, which seems correct in a mathematical sense, provided the word "general" is understood to mean "broader" rather than "more usual."

The present paper and the discussion are an illustration of the great need of fixing the precise definitions of terms. One has only to look at the definitions of elasticity, elastic, modulus, stress, and strain in the Century Dictionary, to see the very different senses in which these terms are used by authorities.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, October 6, 1906.—President McBride in the chair. Seventy-six members and visitors present.

The Secretary announced the death of Mr. Frank T. Weiler, active member, on June 11, 1906.

The Tellers reported the election of Emmett B. Carter and S. K. Thompson to active membership and Philip M. Guba to junior membership.

Notice was given that a motion would be brought up at the next business meeting that the Club should take some action on the suggestion of a restaurant in the cellar of the Club House.

Mr. H. G. Perring read a paper on "The Design and Construction of a Reinforced Concrete Apartment House."

Business Meeting, October 20, 1906.—President McBride in the chair. Sixty-two members and visitors present.

The Secretary announced the death of Mr. Louis Schutte, active member, on September 29, 1906.

It was moved and carried that a Committee be appointed to consider the advisability of converting the basement of the Club House into a lunch room.

Mr. John C. Trautwine, Jr. read a paper on "Further Note on the Summation of Stresses in Certain Structures."

Business Meeting, November 3, 1906.—The meeting was held at the new Engineering Building of the University of Pennsylvania. President McBride in the chair. One hundred and forty-one members and visitors present.

The Nominating Committee presented the following nominations for officers:

For President,........................Henry H. Quimby.
For Vice-President,....................W. P. Dallett.
For Secretary,........................Walter Loring Webb.
For Treasurer,........................Geo. T. Gwilliam.
For Directors,...................... J. W. Ledoux. John T. Loomis. Emile G. Perrot.

President McBride then made a short address, which was followed by addresses from Dr. Spangler and Dr. Marburg.

The Tellers reported the election of Emil Schlichting to active membership and Harold D. Elfreth to junior membership.

The following committee was appointed to consider the advisability of having daily lunch in the Club: Mr. Perrot, Chairman, and Messrs. Perring, Loomis, Gwilliam, and Dallett.

Regular Meeting, November 17, 1906.—President McBride in the chair. Sixty-five members and visitors present.

Mr. P. A. Maignen read a paper on "Different Methods of Purifying Water, with a Reference to His Own Inventions."

Business Meeting, December 1, 1906.—President McBride in the chair. Fifty-seven members and visitors present.

The President announced that Mr. H. G. Perring had been advanced to active membership.

Mr. Maignen's paper on "Purifying Water" was discussed.

The Tellers reported the election of Calvin P. Bascom and J. L. Warner to active membership.

Business Meeting, December 15, 1906.—President McBride in the chair. Eighty-two members and visitors present.

Mr. Perrot, as Chairman of the Committee on Reinforced Concrete, announced that a report would be made in a month or two.

Mr. J. B. Strauss read a paper on "Bascule Bridges." A vote of thanks to Mr. Strauss was unanimously passed.

Business Meeting, January 5, 1907.—President McBride in the chair. Eighty-seven members and visitors present.

The Secretary announced the deaths of Mr. John S. B. Nagle, associate member, on October 25, 1906, Mr. A. J. Cassatt, active member, on December 28, 1906, and Mr. Wm. G. Neilson, active member, on December 29, 1906.

The Secretary reported that the following members had been advanced to the active list: J. W. Blizard, Franklin S. Chambers, Lewis R. Ferguson, J. Scott Fowler, Chas. B. Gamble, Louis H. Losse, John W. Meyer, Harry S. Parks, H. Albert Rogers, and Howard L. Yearsley.

Mr. Wm. M. White read a paper on "The Power Plant of the Electric Development Co. of Ontario, Ltd."

The Tellers reported the election of John J. Gibson and Frank F. Glenn to active membership.

Annual Meeting, January 19, 1907.—President McBride in the chair. Eighty-eight members and visitors present.

The Treasurer reported the names of three active members and one associate member who had been dropped from the rolls on account of non-payment of dues.

President McBride then read the annual presidential address.

It was moved and carried that the report of the Board of Directors and also that of the Treasurer be received and adopted as presented.

The Tellers reported the election of the following officers for 1907: President, Henry H. Quimby; Vice-President, W. P. Dallett; Secretary, Walter Loring Webb; Treasurer, Geo. T. Gwilliam; Directors, J. W. Ledoux, John T. Loomis, and Emile G. Perrot.

Mr. McBride made a few remarks thanking the Club for the courtesy and assistance he had received during the years that he had held office.

President Quimby then assumed the chair and made a short address.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Regular Meeting, October 20, 1906.—Present: President McBride, Directors Dallett, Dodge, Easby, Loomis, and Quimby, and the Treasurer and Secretary.

The report of the Treasurer for the month of September was read and accepted as follows:

Balance August 31, 1906,	$3803.14
September Receipts,	209.29
	$4012.43
September Disbursements,	590.18
Balance September 30, 1906,	$3422.25

Upon discussion of the resignation of Mr. Jos. B. King as Vice-President, it was moved and carried that Mr. King should be asked to reconsider his resignation.

The following resignations were accepted: D. McN. Stauffer, S. H. Goodenough, and Charles Piez; and that of John Nazel was accepted as of December 31, 1905.

Regular Meeting, November 17, 1906.—Present: Directors Easby, Dallett, Dodge, Loomis, and Quimby, and the Secretary.

The report of the Treasurer for the month of October was read and accepted as follows:

Balance September 30, 1906,	$3422.25
October Receipts,	262.50
	$3684.75
October Disbursements,	454.30
Balance October 31, 1906,	$3230.45

The Secretary read a letter from Mr. Jos. B. King, stating that he would withdraw his resignation as Vice-President.

Permission was granted to the Illuminating Engineering Society to hold regular meetings at the Club House on the third Friday of each month.

The resignation of Mr. F. L. Hand was accepted.

Regular Meeting, December 15, 1906.—Present: President McBride, Vice-President Devereux, Directors Dallett, Dodge, Easby, Loomis, and Quimby, and the Secretary.

The report of the Treasurer for the month of November was read and accepted as follows:

Balance October 31, 1906,	$3230.45
November Receipts,	693.17
	$3923.62
November Disbursements,	477.61
Balance November 30, 1906,	$3446.01

It was moved and carried that the Engineers' Club should exchange Club House privileges with the Rochester Engineering Society.

It was moved and carried that notices of meetings should be sent to technical institutions whose principals would guarantee to post the same on their bulletin boards.

It was moved and carried that the offer of the Germania Press regarding a report by German railroad experts on the condition of American railroads be declined.

It was moved and carried that the subject of prompt acceptance of membership by new members be referred to the incoming board.

Special Meeting, January 5, 1907.—Present: President McBride, Vice-President Devereux, Directors Dallett, Dodge, Easby, Head, Loomis, and Quimby, and the Secretary and Treasurer.

The report of the Treasurer for the month of December was read and accepted as follows:

Balance November 30, 1906,	$3446.01
December Receipts,	1220.37
	$4666.38
December Disbursements,	742.71
Balance December 31, 1906,	$3923.67

It was moved and carried that the subject of the next Directory containing a list of books in the Library be left to the incoming Board of Directors.

It was moved and carried that the Library Committee should endeavor to obtain a copy of the report on "The Water Supply of San Francisco," by Herman Schussler, Chief Engineer of the Spring Valley Water Company.

The report of the Executive Committee for the year 1906 was then read. It was moved and carried that the words "One of the Founders" be inserted after the name of Wm. G. Neilson in the list of deaths during the year.

The following resignations were accepted: F. H. Lewis, Edward Page, Arthur H. Pratt, Irving B. Thomas, Edw. W. Vaill, Jr., Wilmer M. Webb, and A. H. Whiteside.

Regular Meeting, January 19, 1907.—Present: President McBride, Directors Dallett, Dodge, Easby, Head, Loomis, and Quimby, and the Secretary and Treasurer.

The certification of the Auditors on the Treasurer's report was presented to the Board.

It was ordered that the regular meeting of February 2d be made a business meeting.

It was moved and carried that the resignation of Mr. O. G. Smith be laid on

the table while the Secretary endeavors to induce Mr. Smith to withdraw his resignation, and become a Non-Resident member.

The following resignations were accepted: Edw. C. Moore, C. D. Hoyt, and Wm. Hogg Baker.

ADDITIONS TO THE GENERAL LIBRARY.

FROM STATE GEOLOGIST, N. J.

Annual Report of the State Geological Survey for 1905.

FROM CITY ENGINEER.

Annual Report of the City Engineer of the City of Toronto for 1905.

FROM GEOLOGICAL SURVEY OF WESTERN AUSTRALIA.

Bulletins Nos. 21 and 22 with Maps.

FROM E. LUDLOW.

Les Gisemints Carbonifreres De Coahuila.

FROM NATIONAL ASSOCIATION OF STATIONARY ENGINEERS.

Report of the License Committee of the N. A. S. E.

FROM GEOLOGICAL SURVEY OF CANADA.

Report for 1902 and 1903, Vol. XXV.

FROM GEO. S. WEBSTER, CHIEF ENGINEER.

Annual Report, Bureau of Surveys, Phila., 1905.

FROM UNIVERSAL PORTLAND CEMENT CO.

The Process of Concreting.

FROM A. GIBB MAITLAND, GOVERNMENT GEOLOGIST.

Mineral Resources of the Pilbara Goldfield.

FROM GEOLOGICAL SURVEY OF OHIO.

Bibliography of Ohio Geology.

FROM AMERICAN PHILOSOPHICAL SOCIETY.

The Franklin Bi-Centennial Celebration.

FROM LIBRARY OF CONGRESS.

Report of the Library of Congress for the year 1906.

FROM PHILADELPHIA BRANCH OF THE AMERICAN CHEMICAL SOCIETY.

Chemical Abstracts, Vol, No. 1.

THE ENGINEERS' CLUB OF PHILADELPHIA,

House, No. 1122 Girard Street,

PHILADELPHIA, PA.

ANNUAL REPORT OF THE BOARD OF DIRECTORS

For the Fiscal Year 1906

JANUARY 7, 1907.

TO THE ENGINEERS' CLUB OF PHILADELPHIA:

In compliance with the requirements of the By-Laws, the Board of Directors offers the following report for the year ending December 31, 1906:

Eighteen regular meetings of the Club were held, at which the maximum attendance was 141 and the average 79, a decrease in average attendance of 18 members. Ten stated, one adjourned, and two special meetings of the Board of Directors were held.

Twenty-eight active, 14 junior, and 3 associate members were elected; 14 active and 2 associate members resigned (1 of which was as of December 31, 1905); 3 active members were reinstated; 3 active and 1 associate member were dropped from the rolls; and 11 junior members were advanced to the active list.

The record of deaths is:

A. J. Cassatt, Active Member, died December 28, 1906.
E. T. Hannam, Active Member, died August 18, 1906.
Max Livingston, Active Member, died February 16, 1906.
Jno. S. B. Nagle, Associate Member, died October 25, 1906.
Wm. G. Neilson, Active Member (one of the Founders), died December 29, 1906.
Louis Schutte, Active Member, died September 29, 1906.
Theodore Spencer, Active Member, died January 28, 1906.
Frank T. Weiler, Active Member, died June 11, 1906.

	1905.			1906.		
Class.	*Resident.*	*Non-Resident.*	*Total.*	*Resident.*	*Non-Resident.*	*Total.*
Honorary	2	4	6	2	4	6
Active	333	113	446	347	117	464
Junior	18	5	23	19	6	25
Associate	24	...	24	24	...	24
	377	122	499	392	127	519

The following papers have been presented:

January 6th.	The Raymond System of Concrete Piling.	Percy H. Wilson.
	Saving of Power House Sea Wall at Annapolis, Md.	Percy H. Wilson.
January 20th.	Address of Retiring President.	Silas G. Comfort.
February 3d.	The Telephone System of To-day.	C. J. H. Woodbury.
February 17th.	By-Product Coke Ovens in America; Past, Present, and Future.	Edwin A. Moore.
March 3d.	The Economical Distribution of Distilled Water, and Its Applications.	Henry Leffmann.
March 17th.	The New Sea Wall at Annapolis, Md.	Harrison W. Latta.
April 7th.	Garbage Disposal by Reduction Methods.	D. Robert Yarnall.
April 21st.	Mechanical Integration, with a Special Reference to the Integraph.	C. O. Mailloux.
May 5th.	Corrugated Concrete Piles.	Frank B. Gilbreth.
May 19th.	The Water Works at Charleston, S. C.	J. W. Ledoux.
	A Comparison of the Cost of Pumping Machinery, Driven by Steam and Oil Engines.	Francis Head.
June 2d.	The Foreman; His Training, Work, and Relation to Maintenance of Way Organization.	S. W. Kapp.
September 15th.	Denatured Alcohol; Its Manufacture and Some of Its Applications.	Henry Leffmann.
October 6th.	The Design and Construction of a Reinforced Concrete Apartment House.	H. G. Perring.
October 20th.	Further Note on the Summation of Stresses in Certain Structures.	John C. Trautwine, Jr.
November 3d.	Meeting at University of Pennsylvania.	Edgar Marburg, H. W. Spangler, and Thos. C. McBride.
November 17th.	Different Methods of Purifying Water, with a Reference to His Own Inventions.	P. A. Maignen.
December 1st.	Discussion of the above paper.	
December 15th.	Bascule Bridges.	J. B. Strauss.

On November 3d, the regular meeting of the Club was held at the new Engineering Building of the University of Pennsylvania, as arranged by the Information Committee.

The Library Committee has purchased a set of the "New International Ency-

clopedia" and also a set of the "Americana," both of which have been placed in the Reference Room.

The Treasurer's statement of receipts and expenditures has been examined and found correct. A statement is herewith submitted of the net expenditures for the year; also a comparative statement of the assets and liabilities at the beginning and end of the year.

NET EXPENDITURES FOR 1906.

House	$2459 05
Library	200 00
Proceedings and Directory	189 77
Information	72 95
Office	654 16
Salaries	1617 50
	$5193 43

ASSETS.

	Jan. 1, 1906.	*Dec. 31, 1906.*
Furniture and fixtures, as per appraisement	$1900 00	$1750 00
Library, as per appraisement	2100 00	2000 00
U. S. Bond, issue of 1898 (par $500) market value	517 50	513 75
On deposit, bearing interest at 3 per cent	595 90	2143 92
On deposit, bearing interest at 2 per cent. (including advance dues)	2139 56	1779 75
Outstanding dues considered good and collectable (being dues for the years 1905 and 1906 respectively remaining unpaid on the 31st of December by members in good standing)	445 00	350 00
	$7697 96	$8537 42

LIABILITIES.

Advance dues collected and included in above bank deposits (being dues for 1906 and 1907 respectively)	955 00	510 00
NET ASSETS	$6742 96	$8027 42

Respectfully submitted,

THOS. C. MCBRIDE, *President.*

WALTER LORING WEBB, *Secretary.*

REPORT OF THE TREASURER FOR THE FISCAL YEAR 1906.

Receipts.

Initiation fees (45)	$225 00	
1904 Dues	30 00	
1905 Dues	420 00	
1906 Dues	5090 00	
1907 Dues	510 00	
		$6275 00
Proceedings:		
Advertisements	$334 00	
Sales	73 50	
Reprints	50 50	
		458 00
House:		
Telephone	$8 43	
Billiards	14 75	
		23 18
Sales of Old Periodicals		50 00
1906 Directory		720 00
Interest on Deposits		91 64
Interest on Investment		15 00
Total Receipts		$7632 82
CASH BALANCE DEC. 31, 1905,		**2735 46**
		$10,368 28

Expenditures.

Salaries:		
Secretary	$360 00	
Treasurer	120 00	
Clerk	540 00	
Janitor	570 00	
		$1617 50
House:		
Rent	$1260 00	
Coal	108 80	
Gas and Electric Light	113 29	
Ice	38 55	
Supplies and Repairs	202 62	
Telephone	169 97	
Insurance	9 00	
Luncheons	580 00	
		2482 23
Office Expenses		654 16
Proceedings		958 84
Information Committee		72 95
Library Committee		250 00
1906 Directory		408 93
Total Disbursements		$6444 61
CASH BALANCE DEC. 31, 1906,		**3923 67**
		$10,368 28

Respectfully submitted,

GEO. T. GWILLIAM, *Treasurer.*

PHILADELPHIA, January 3, 1907.

We have examined the books and accounts of the Treasurer, compared them with the original vouchers, checks, and bank books, and found them to correspond with the Treasurer's Statement submitted above.

H. W. SPANGLER,
W. B. RIEGNER,
RICHARD L. HUMPHREY, } *Auditors.*

January 12, 1907.

Thos. C. McBride

Editors of other technical journals are invited to reprint articles from this journal, provided due credit be given the PROCEEDINGS.

PROCEEDINGS
OF
THE ENGINEERS' CLUB
OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. XXIV. APRIL, 1907. No. 2

PRESIDENT'S ADDRESS.

RECENT DEVELOPMENTS IN LARGE CENTRAL ELECTRIC PLANTS.

THOS. C. MCBRIDE.

Delivered January 19, 1907.

THE last few years have seen a very rapid development and some radical changes in large American central electric lighting and electric railway power plants, producing their energy from coal, that seem worthy of more than passing attention. Only six years of our new century have passed, yet the power plant built to-day is entirely different from the plant of the last century. A review of progress in the design of the complete plant necessarily covers a very wide engineering field and so many details that only the more important of these details can be considered, and those but briefly. Much of this development has had in view lessening the cost of the production and distribution of electric energy, but considerable of it has been forced on the power station situation by a very rapid increase in the demand for electric power and light.

The word "central," inherited from the electric lighting plant of a few years ago, is an awkward term, particularly since electric railway developments have necessitated large alternating current power plants distributing power through substations over large areas, which plants are just as much central as their sister lighting plants. Electric plants have been divided into three classes, central, trolley, and

isolated. It is the larger coal-electric power plant of the first two classes that the title of this paper is intended to cover, its station being termed "central."

A complete change in the general scheme of the distribution of electric energy from that which was usual ten years ago has been the principal cause of the very rapid development of the modern "central" electric power plant. Possibly six years ago, surely ten years ago, over three-quarters of the electric energy generated from coal was distributed in the same form in which it was generated and used. An incandescent lighting system meant 110 or 220 volts or thereabouts generated in the station, distributed on the lines and used in the lamps or motors, and a circuit reaching out a mile was considered as much as it was advisable to attempt. Trolley work meant 500 volt generators, feeders, and lines, and arc lighting meant just as surely constant current, series distribution. The interior of a power house for any one of these systems indicated exactly which service it was supplying. These power plants were necessarily located near their load centers, and we therefore find them in the midst of residence and business districts, central in fact as well as in name. It seems rather remarkable that so many of these plants have been located at points requiring the carting of coal, and out of reach of condensing and cheap feed water supply when other locations but a few hundred feet away would have given them a convenient supply of both fuel and water, indicating that the builders of these old plants either did not appreciate the advantages of convenient fuel and water supply, or else did not anticipate a growth to a size where their hauling bills or the economies of condensing operation would be worthy of consideration.

The interior of the great "central" power stations we are building to-day gives no indication of the particular service for which their energy is being used. Power for railway, incandescent, or arc lighting is generated in the form of high potential alternating electric current, and distributed to substations where it is transformed into the particular kind of current desired. The incandescent station and the trolley station with their heavy investments in copper and the arc station with its jack shafts, belts, and large number of small machines have given way or are giving way to the alternating current station with its uniformity of plan and construction which seems to be gradually reaching a standard form. The high potential at which these modern plants distribute their current not only permits of their location where fuel and condensing water supply are convenient, but also enables them to cover economically larger areas and distances,

permitting the replacement of a number of smaller plants by a single large plant with all the attendant economies in first cost, maintenance, and operation.

The change from the old system to the new, with its high tension alternating current, afterwards transformed for its own particular use, seemed to set in most rapidly about the beginning of our century. The alternating current had long been acknowledged as preferable for distribution, but trouble in paralleling generators had prevented its extensive adoption. It will be appreciated that successful parallel operation is necessary for economy, not only in generation but also in distribution of electric energy. Generators must operate successfully in parallel if they are to be loaded to their best efficiency, and if an efficient and simple system of distributing mains is to be employed. Attempts to use a very high frequency seem to have been the principal cause of the difficulty with parallel operation in the early years of the alternating current. Fifteen to eighteen years ago 133 cycles was usual. That engineers were not sure of the success of parallel operation of 60 cycle alternators even with belt-driven machines at the time of the Chicago Exposition is evidenced by the fact that the lighting plant of the Exposition, consisting of ten 750 kw. 60 cycle 150 R. P. M. generators, was deliberately arranged not to run in parallel, at considerable extra expense, for an elaborate switchboard permitting any unit to be connected to any distribution main.

The starting of the Niagara Falls Power Co.'s plant in 1895 marked an epoch in the history of the distribution of electrical energy and established parallel operation with 25 cycles as a commercial success. Even up to a few years ago parallel operation with 60 cycles was difficult and often the cause of much trouble. Recent improvements in generator design have secured successful and reliable parallel operation at 60 cycles and proven this success to be largely an electrical matter and not entirely dependent on uniformity of angular velocity of the prime mover, as was thought a few years ago. Whether this success will result in the more general use of 60 cycle frequency with polyphase currents in power distribution will doubtless be decided in the near future.

The extensive use of the alternating current in the United States as compared to the direct even as long ago as 1902 is shown by two "Special Reports" issued by the Department of Commerce and Labor, Bureau of the Census, one published in 1905, "Central Electric Light and Power Stations," the other "Street and Electric Railways,"

published 1904. Table No. 1 of the former and Table 96 of the latter are given with their totals.

CENSUS OF JUNE, 1902. GENERATING PLANT EQUIPMENT.

Dynamos.	Table 1.	Table 96.		Totals.
Direct Current Constant Voltage:				
Number...........	3,823	2,861		
Horse Power......	442,446	972,314		
Direct Current Constant Amperage:			Direct Current:	
Number...........	3,539		Number.........	10,223
Horse Power.......	195,531		Horse Power.....	1,610,291
Alternating and Polyphase Current:			Alternating Current:	
Number...........	5,122	441	Number.........	5,563
Horse Power......	987,003	231,924	Horse Power.....	1,218,927
Output of stations in kw. hours for year (June 30, 1901, to June 30, 1902)...............	2,507,051,115	2,261,484,397		4,768,535,512

These tables show the predominence of the alternating current in 1902 in the lighting and power field, but that the electric railway was still largely depending on the direct current for its power. It is difficult to estimate the relative growth of high tension alternating current and direct current generation since this report. About 900,000 kw. capacity in steam turbines have been built in this country. As practically all of these were likely connected to alternating current generators, and as a very considerable capacity of steam engine driven alternating current generators have been built since 1902, we may safely conclude that the alternating current central electric and railway generator capacity of the country has been much more than doubled in the last four and one-half years.

The maximum voltages of the distribution systems of the few large American coal-electric alternating current power plants in existence at the beginning of our century, barring one or two exceptions, was 6,600. The Metropolitan Street Railway, New York, power house and the New York Edison power house at Thirty-ninth St. are examples of plants of the kind under consideration that were using this voltage. The Manhattan Railway Co. plant, started in 1901, nearly doubled this amount, distributing at 11,000 volts, and the direct generation of this voltage on the dynamos was considered a very striking electrical feature. Since the Manhattan there has been practically no increase in the voltages adopted for the distribution systems of the railway and lighting plants of our largest cities receiving their current from power stations within them; 13,200 volts being the maximum in use for this class of service. As it is altogether likely that 11,000 to 13,200 volts will remain the maximum for distribution over the area of our large cities, because these pressures are ample for economy and

offer the advantage of safe direct generation, it is much to be regretted that some standard figure was not adopted long ago for the sake of simplicity in the manufacture and operation of electrical machinery.

The coal-electric power plant has recently been called upon to deliver electric energy over long distances in a number of heavy electric traction projects. These distances have been so great that voltages as high as those until recently found only in our hydro-electric long distance transmission plants have been necessary. The coal-electric power station and the high voltage long distance transmission line, although developed separately, have each been developed so well that the success of their combination has been a foregone conclusion. There is now no difficulty in securing well tried out electrical apparatus which would operate economically 100, 200, or even 300 miles of railway from one power house. Projects like that proposing to generate electric power for cities like Philadelphia and New York at the coal mines seem quite feasible if only a sufficiently large market for the power is obtainable. The coal bills of large "central" stations in these cities represent about 70 per cent. of the cost of energy at the switchboard, not including fixed charges. About two-thirds of the cost of the coal is freight. Fixed charges and many of the other expenses of operation would be considerably less in the open country than in our large cities. It may therefore safely be concluded that power can be produced at the mines for less than 50 per cent. of the cost of its production in the cities mentioned.

It is likely that 50,000 volts, or thereabouts, will be more than ample pressure for most projects of distribution from coal-electric generating plants, as this will economically cover a radius of, say, 150 miles, but occasional coal-electric projects are not unlikely to present in the near future, as hydro-electric projects are now presenting problems whose solutions will be dependent upon a cheaper and more efficient method of transmission than is obtained with the voltages with which we are now familiar. Present knowledge indicates that this can only be obtained by largely increased pressures. Problems like Victoria Falls, talked of so much abroad, call for 100,000 to 150,000 volts. Electrical manufacturers have already catalogued and are ready to supply switches and lightning arresters for 125,000 volts. Experimental lines carrying 100,000 volts have been tried in Europe and found practicable. The maximum of 40,000 volts in 1901, with a year or two pause at 60,000 volts, has now gone to 75,000 volts at the Edison Co., California, plant. There are so many opportunities for considerably higher voltages than the present maximum that a

much more rapid increase in the maximum voltage may be looked for in the next few years.

In connection with the study of increased voltages for the economical transmission of large amounts of power to great distances the direct current system of M. Réné Thury is of interest. This plan contemplates the use of a number of carefully insulated direct current constant amperage generators in series, furnishing this constant amperage to the line at a voltage depending on the power being transmitted, the receiving station consisting of a number of motors in series. This system is quite flexible in permitting the throwing in or out of additional units as their power (voltage) may be required, and contemplates grounding stations to cut out any particular length of wire that may be in trouble, the earth temporarily taking its place. Naturally for the same factor of safety this system can carry more power (higher pressure) on a given line than if alternating current was used, and only two wires are required. The Thury plant for Lyons, France, although small as plants go in this country, is an interesting example of this system. This plant carries 75 amperes and voltages varying up to 60,000, according to the call for power, and has sixteen 400 horse power 3900 (maximum) volt generators in series. The system gives promise of being quite useful for large powers and long distances, particularly where the power is to be generated at one point and delivered to another point.

The general scheme of distribution by the alternating current as used by most of our large "central" electric power plants involves so many transformations of energy from one kind to another that it is far from ideal. The complication of the system of the distribution of power by the alternating current is so great that a grave question has arisen as to just how the load, particularly of a large lighting system, could be promptly picked up again if for any reason the entire system was shut down even for a moment. Considering these complications it is small wonder that a few plants, even some of large size like the Boston Elevated Railway Company's system, continue to use and to increase their number of small direct current stations.

While the complexity of the distribution system required for most alternating current plants is a disadvantage, the ease with which the potential of the alternating current may be stepped up or down without rotative machinery and of transformation of one supply current to a variety of forms, together with the possibility of generation at high potential, make it altogether likely that the ratio of the alternating

current used for distribution as compared to the direct current will continue to increase even more rapidly than in the last few years.

Substations are demanding increased attention on account of the great amount of machinery in them and their frequently being supplied with storage batteries. Many recent substations are of very large size, some as large as the average central station of the last century, in fact many old central stations are now used as substations, their original machinery being held as reserve.

The substations of the N. Y. C. and H. R. R. and the West Jersey and Seashore are examples of modern substations for heavy electric traction, and illustrate the great amount of power now being distributed by their means. Two of the former have each three 1,500 kw. rotary converters, the balance three 1,000 kw. and all have room for two more. These substations each have storage battery equipments designed not only to take the fluctuations in the load, but large enough to run the system for one hour. One of these batteries has a discharge rate of 4,020 amperes, another 3,750, another 3,000, and the remaining stations 2,250 amperes. These substations receive three phase 25 cycle current at 11,000 volts, and deliver 666 volt direct current to the third rail. The West Jersey & Seashore substations receive three phase 25 cycle current at 33,000 volts, and deliver 650 volt current to the third rail. These substations generally have each two 750 kw. rotaries with room for a third.

Storage batteries, although vigorously condemned by many, are being more generally adopted and are rapidly assuming an important place in the organization of large lighting and railway plants. The usefulness of the storage battery has been much increased, particularly in the last year, by a great increase in the possible discharge rate for short periods, and some very large storage battery plants have recently been installed. Storage batteries are used as a reserve supply of current for excitation and to carry peaks, and have been installed in some cases with a capacity large enough to act as a reserve supply for the station itself should either all or part of its machinery or its distributing mains be out of commission. With modern rotaries, substation batteries will return power to the alternating mains when the power station itself or other substations are in need of assistance. The storage battery in connection with automatic boosters and rotary converters is being used to even the load on power stations as a means of increasing their economies of output and first cost, and it is now claimed that storage batteries with modern machinery can be regulated

so that the call on the power station will vary but a few per cent. in spite of enormous fluctuations of the final load.

It is not at all unlikely that the near future may see the storage battery applied to strictly alternating current plants. The present year will be rich in developments of alternating current traction, and where railways may need substations with step-down transformers at distant points, it is not impossible that it would be advisable for these distant stations to be supplied with batteries and rotaries that will run inverted, and also, possibly, automatic boosters. Such an arrangement would not only permit of the distant substation furnishing for a short period of time a relatively large amount of power, even though supplied through a small line, but would also ensure the supply of power for a short time in case the line had failed.

The larger territory that can be economically supplied by the alternating current from a single power plant and the great demand for electrical power and light have resulted in power houses of enormous size, some of the largest single plants are as follows:

	Kw. Capacity at Present.	Kw. Capacity Ultimate.
Chicago Edison (Fisk St.),	52,000	100,000
N. Y. Edison (old Waterside Station),	60,000	60,000
N. Y. Edison (new Waterside Station),	24,000	80,000
Interborough Rapid Transit Co., Fifty-ninth St.,	....	60,000
Interborough Rapid Transit Co., Seventy-fourth St.,	40,000	40,000
N. Y. St. Rwy. Co., Ninty-sixth St.,	38,500	38,500
N. Y. St. Rwy. Co., Kingsbridge,	48,000	48,000
Boston Edison,	15,000	60,000
N. Y. C. & H. R. R. (Port Morris),	20,000	30,000
Penna. R. R. (Long Island),	16,500	33,000

The figures used in these tables are based on builders' nominal capacity ratings, some of the stations were not originally designed for the full ultimate capacities mentioned, but the use of steam turbines instead of steam engines, and the use of larger size steam turbine units than could be had a year or two ago, has resulted in changed plans and installation of greater capacity.

The prime mover question has without doubt furnished the most interesting power station development of our new century. We started our century with our old friend the steam engine in complete possession of the field, one hundred and twenty-five years since Watt, almost sixty years since Corliss had given the steam engine a place which seemed impregnable, yet our twentieth century, with a thought though many times older but until 1884 unstudied by modern science, has given the steam turbine of today a place beside, if not ahead, of

the steam engine for central power house work, made a good start with the large gas engine, and started serious study of the gas turbine.

The first year or two of our century witnessed remarkable developments in the steam engine field, in the rapid increase in size of units. The two 4,000 horse power engines for the Bay Ridge Station of the Kings County E. L. & P. Co., started early in 1901, were considered large units, but were rapidly followed by 5.000 horse power units for the Kingsbridge Power House of the New York Metropolitan Railway and the Boston Elevated, and the eight 6,500 horse power engines for the New York Edison, and before the end of 1901 the first 7.500 horse power unit of the Manhattan Railway Co., had been started.

A number of engines of the same general type and size as the Manhattan have since been built, notably nine for the New York Subway power house (The Interborough Rapid Transit Co.); but no engines of any greater capacity for power house work. As these engines probably represent the final development in size of the steam engine for electrical power house work a short description may be of interest. Of 7,500 H. P. at best efficiency and 11,000 maximum H. P. they were guaranteed not to require more than $12\frac{1}{4}$ pounds of steam per I. H. P. at nominal rating with 175 pounds saturated steam and 26 inches vacuum. A comparison of their dimensions with those of the Subway Station engines, and some engines built lately for the electric light and trolley stations of Baltimore follow, the first two columns being taken from a publication by the Interborough Rapid Transit Co. and the last from data furnished by McIntosh, Seymour & Co., the builders of the Baltimore engines.

	Manhattan.	Subway.	Baltimore.
Diameter of H. P. cylinders (inches)	44	42	38
Diameter of L. P. cylinders (inches)	88	86	78
Stroke (inches)	60	60	56
Speed (R. P. M.)	75	75	94
Steam pressure at throttle	150	175	165
I. H. P. at best efficiency	7500	7500	7500
Diameter L. P. piston rods (inches)	8	10	8
Diameter H. P. piston rods (inches)	8	10	8
Diameter crank pins (inches)	18	20	18
Length crank pins (inches)	18	18	18
Type of L. P. valves	Double Ported Corliss	Single Ported Corliss	Multi-ported Gridiron
Type of H. P. valves	Corliss	Poppet	Gridiron
Diameter of shaft in journals (inches)	34	34	28
Length of journals (inches)	60	60	54
Diameter shaft in hub of revolving element	$37\frac{1}{16}$	$37\frac{1}{16}$	32

The steam turbine was not known in the American "central" power station in the last century. During April, 1901, a 1,500 kw. Westinghouse-Parsons turbine was started in Hartford, Conn. Since 1901 the use of the steam turbine has become almost universal, and but few large steam engine units have been ordered for large "central" power plants. The report of the turbine committee of the National Electric Light Association for June, 1905, states that there were then in operation 224 turbines of a total of over 350,000 kw. capacity, and that the total capacity shipped or on order June, 1906, was about 931,000 kw. As this figure is about equal to the total central station alternating current generator capacity of the country stated by the U. S. Census for 1902 it presents a remarkable showing. Almost without exception large new power stations as well as any large additions to old stations are being furnished with turbines, and during the last year or two we have seen the advent of turbine-driven station auxiliaries. Turbines as large as 9,000 kw. nominal capacity have been running for some months and 10,000 kw. turbines are being built.

The advent of the steam turbine has developed the use in the United States of the super-heater, and of a special form of condenser for high vacuum. This high vacuum has required at least twice the amount of condensing water needed for the vacuum usual with the steam engine, and all the extra cost of conduits, pumps, etc., to handle it. While the turbines themselves require practically no constant attention, the auxiliaries necessary are so large and numerous that their cost for attendance and oil is considerable. Notwithstanding all this, the low first cost, the low steam consumption through a wide range of load, the high rotative speed and uniform angular velocity, the small floor space and foundations required, and the simplicity of the steam turbine have in a very few years made it for electric work the prime mover of today. The large steam turbine has become such a familiar sight in central electric power houses that it seems scarcely possible that it is only three years and three months since the first 5,000 kw. turbine was started in this country. This machine was started in the Fisk St. Station of the Chicago Edison October, 1903, and followed in a few months by another. The next 5,000 kw. units to be started were at the Boston Edison; one in October and another in November, 1904.

The rapidity of the successful development and introduction of the steam turbine in this country has earned great admiration for those in charge of this work. Considering the amount of money involved,

their confidence in their calculations, often made with little experimental basis and in the face of predictions of failure from not a few engineers of note, must have been absolute.

The large gas engine has not yet made any impression on strictly "central" station practice in the United States. Electric stations with units up to 500 H. P. are in successful operation, mostly furnishing power for electric railways, and are said to be doing very satisfactory work. The only large gas engine as yet started in "central" station work of which the writer is informed is one of the lot of four 5,400 H. P. engines furnished the California Gas & Electric Corporation by The Snow Steam Pump Works. Three of these engines have been erected in San Francisco and the fourth is being shipped to Oakland. The first of the San Francisco engines has been operating very satisfactorily, carrying loads approaching its full load in parallel with water wheels and a steam plant owned by this Corporation. The builders of these engines state that the starting and operating of this engine and the recent starting of the second engine has been more satisfactory than they even dared to hope, particularly in view of the kind of gas used.

An investigation of the present status of the large gas engine in the United States indicates that it is well worthy of consideration for "central" power station work. It is not generally known that the large gas engine is already well developed in this country, but it is a fact that a number of large engines have been in successful operation for some years. The first of these large engines were built by The Snow Steam Pump Works, who have built and in operation, or about ready to start, 53,400 B. H. P. of gas engines, and have in various stages of completion 50,450 B. H. P., ranging in size from 60 to 3,300 B. H. P. Some of their large engines have been in service since 1900, two 4,000 B. H. P. engines have been in service since the summer of 1904. Several record runs of 50 to 90 days without a shut-down have been reported, performance which would not now be considered exceptional should circumstances warrant so long a continuous run.

The gas engine plant of the Lackawanna Steel Co. at Buffalo with its 32,000 H. P. in blowing engines and 8,000 H. P. direct connected to electric generators has been in operation for two or three years. The blowing engines are of 2,000 H. P. each and the direct connected engines 1,000 H. P. each.

No greater index of the confidence of engineers who have investigated the large gas engine in its future can be found than in the great number of large engines that have recently been ordered. That engineers

are fully satisfied that the large gas engines can be depended upon, for satisfactory continuous operation is demonstrated by such orders as that of the U. S. Steel Corporation for its new steel plant at Gary, where continuity of operation will be vital.

The following list of large gas engines ordered recently are nearly all still in the shops of the builders, but few having yet been shipped.

LARGE GAS ENGINES RECENTLY ORDERED.

SNOW STEAM PUMP WORKS, BUILDER.

NUMBER.	CAPACITY.	NAME OF PURCHASER.
2	3000 H. P.	Illinois Steel Co.
4	1100 H. P.	Iola Portland Cement Co.
2	1100 H. P.	Logan Natural Gas Co.
5	1100 H. P.	Kaw Gas Co.
4	1100 H. P.	Wheeling Natural Gas Co.
2	810 H. P.	Charlotte Consolidated Construction Co.
2	800 H. P.	Charleston & Summerville Electric R. R.
2	3300 H. P.	Duquesne Steel Co.
4	3000 H. P.	Duquesne Steel Co.
3	800 H. P.	St. Joe Lead Co.
3	800 H. P.	Doe Run Lead Co.
4	3300 H. P.	Carnegie Steel Co.

WESTINGHOUSE MACHINE CO., BUILDER.

NUMBER.	CAPACITY.	NAME OF PURCHASER.
8	2500 H. P.	Indiana Steel Co.
2	2200 H. P.	Carnegie Steel Co.
1	3000 H. P.	Carnegie Steel Co.

ALLIS-CHALMERS CO., BUILDERS.

NUMBER.	CAPACITY.	NAME OF PURCHASER.
7	2000 Kw.	Indiana Steel Co.
2	2000 Kw.	Indiana Steel Co.
2	3000 H. P.	Illinois Steel Co.
3	1500 H. P.	Milwaukee Northern Electric Co.
1	3000 H. P.	Carnegie Steel Co.
4	3000 H. P.	Carnegie Steel Co.
1	1500 H. P.	National Tube Co., McKeesport.
2	2000 Kw.	Carnegie Steel Co., Homestead.

Much has been published to show the comparative first cost and cost of operation of gas engine and steam plants, but as few of these figures have been based on the use of large gas engine units estimates have been prepared on a 16,000 B. H. P. gas engine gas producer plant. This estimate contemplates the provision of coal-handling machinery and coal storage in the building.

The figures of first cost are on two types of building, each complete with crane, but do not include the cost of land. The operating costs are based on cost of power at the switchboard with maintenance, but do not include interest, depreciation, taxes, insurance, etc., this being a convenient method of comparison of different plants.

COST OF INSTALLATION.

16,000 B. H. P. GAS ENGINE PLANT WITH PRODUCERS IN FIRE PROOF BUILDING.

Four—4000 B. H. P. Gas Engines	$455,000
Four—4000 B. H. P. Producers	192,000
Four—3000 kw. Generators, 60 cycle	128,000
Station equipment, oil pumps and filters, jacket water pumps, piping, wiring and switchboard	60,000
Engine foundations 4 x 600 cu. yds. concrete	12,000
Crane and runway	15,000
Buildings { Engine room 95 ft. x 180 ft.	102,000
Buildings { Producer room 110 ft. x 180 ft.	108,800
Electric lighting of buildings	4,000
Coal conveying machinery, from cars	15,000
Total	$1,091,800
Cost per kw. nominal capacity	90.98

Cheaper buildings costing, say, $60,000 for the engine and $25,000 for the producer building would reduce the cost of installation to $966,000.00. Cost per kw. nominal capacity, $80.50.

It has been said that large steam turbine plants with coal storage in the building can be built for $80.00 per kw. nominal capacity, but this is doubted, particularly in view of present prices, and the writer has not heard of any plants being built for as little as this. An equipment similar to that figured for the first gas plant would likely cost at least $100.00. A recent plant equivalent of the gas plant housed in the fire proof building cost about $135.00. It may therefore safely be concluded that a gas engine plant with large units can be built for a first cost per kw. nominal capacity somewhat less than a steam plant, the same type of building being used in both cases.

As is usual with large gas engines, these engines are designed for peak overloads of 15 per cent. above the nominal rating stated. This method of rating reveals a limitation of the gas engine, not to its advantage compared to the steam turbine, the latter being ordinarily so rated that it is capable of carrying 50 per cent. over its nominal rating for two hours, and 100 per cent. over for "swings." The possibility of starting the large gas engine in a minute or so however overcomes this objection for all considerations, except that of the greatest loads the station can carry regardless of economy of operation or where it is absolutely impossible to predict very large sudden increases of load. As it is generally possible to predict well in advance the greater load fluctuations of any station, this feature can be neglected, and it is necessary in comparing first costs per kw. nominal capacity only to consider the station as to the maximum total loads it will carry. On account of the small range of overload capacity of gas engines, they are generally provided with generators of somewhat lower nominal rating than their engines, and the 100 per cent.

overload "swings" of turbine practice cannot therefore be applied in comparing the nominal rating of the gas engine. As the gas engine is capable of operating indefinitely at 15 per cent. over nominal rating, it seems only fair that this overload rating should be compared with the 50 per cent. for two hours overload capacity of the steam turbine, in other words, that for comparison of first cost of gas engine and steam stations on the basis of the maximum loads the stations can carry; the gas engine should be considered of only $\frac{115}{150}=76.7$ per cent. of its usual nominal rated capacity. On this basis the first cost of the gas engine station assumed would vary from $\$90.98\times\frac{150}{115}=\$118.94$ to $\$80.50\times\frac{150}{115}=\$105.00$. It is evident that these figures should not be used for comparison, but instead the cost per nominal kw. capacity of the gas engine and the steam turbine plant be compared where the load will not vary more than 15 per cent. above normal and it is desired to load either the gas engine or the steam turbine to the point of maximum economy.

COST OF OPERATION, 16,000 B. H. P. GAS ENGINE PRODUCER PLANT.

Assumed load:
- 100 per cent. during six hours equals four engines full load.
- 75 per cent. during six hours equals four engines three-quarters load.
- 50 per cent. during six hours equals three engines two-thirds load.
- 12½ per cent. during six hours equals one engine one-half load.

Equivalent load factor=59.4 per cent.

Total B. T. U's. required for each of above periods	365 × 6 × 16,000 × 8,900 =	312,000,000,000	B. T. U's.
	365 × 6 × 12,000 × 9,700 =	255,000,000,000	"
	365 × 6 × 8,000 × 10,400 =	182,000,000,000	"
	365 × 6 × 2,000 × 11,300 =	49,500,000,000	"
		798,500,000,000	"
At 80 per cent. producer efficiency...............	=	998,000,000,000	"
Bituminous slack 13,000 B. T. U's. per pound.....	=	76,800,000	pounds.
	=	38,400	tons.

38,400 tons coal at $2.50 = $96,000.00		$96,000.00
Oil, Engine, 2½ gals. per engine per day at 15 cts., see schedule above,		405.00
Oil, Cylinder, 14½ gals. per engine per day at 22 cts., see schedule above,		3,450,00
Waste, 12 bales, 500 pounds at 7 cts..........................		420.00
Power house labor. (8-hour shifts.)		
1 Chief engineer..................................	$2,000.00	
3 Watch engineers................................	3,600.00	
6 Oilers..	4,320.00	
3 Cleaners..	1,620.00	
3 Switchboard operators..........................	2,700.00	
3 Gas makers......................................	2,880.00	
9 Helpers...	6,480.00	
1 Machinist.......................................	960.00	
		24,560.00
		$124,835.00

Total H. P. hrs. per year = 365 × 6 × 38,000 = 83,220,000 = 62,080,000 kw. hrs. Assuming generator efficiency at 93 per cent. the cost of operation at switchboard is

$$\frac{124,835.00}{62,080,000}\times\frac{100}{93}=.216 \text{ cts. per kw. hr.}$$

The following table shows a comparison of the cost of operation of the gas engine plant assumed above and the actual yearly average operating costs of a certain modern steam turbine station well operated and kept in good condition, of a little larger size than this gas engine plant but with approximately the same load factor. Corresponding figures are set opposite for the gas engine station, and as no charge is made against the gas engine plant for cooling water the steam turbine plant is charged with its make-up water only.

	Cents per kw. Hour. Turbine	Gas Engine.
Coal (reduced to $2.50 basis)	.313	.166
Water	.008	..
Labor	.064	.043
Oil and waste	.003	.007
	.388	.216
Maintenance Boiler Room	.017	..
Maintenance Turbine Room	.007	..
Gas engine and producer maintenance assumed same as above	..	.024
Add 2 per cent. to cover cost of driving gas-engine auxiliaries	..	.005
	.412	.245

In comparing the first cost and operating expense of gas engine and steam plants, it should be remembered that all the power required to drive the gas engine auxiliaries must come from the coal pile with no opportunity for reclaiming. The auxiliaries of the steam turbine plant if properly designed theoretically require no extra coal burned for their operation, because practically all of the heat of the steam used in the auxiliaries may be returned to the boilers through the feed water heater. Fortunately for the gas engine very few and inconsiderable auxiliaries are required and it is thought that a provision of 2 per cent. to drive them is ample, a corresponding correction has therefore been made in the estimated cost of operation.

As no data have been obtained on maintenance cost of large gas engines and gas producers in "central" station practice, it has been assumed that this will be the same as that of turbines, their auxiliaries and the boilers.

The saving of fuel of the gas engine as compared to the steam plant can be capitalized to pay for the extra cost of the gas engine plant where it may be desired to compare only their maximum capacity. Presuming to give the steam turbine every advantage that it may be possible to buy large steam turbine plants at $85.00 per kw. nominal

capacity and that this plant may produce a kw. hr. at a yearly average of .4 cts. with the load factor assumed above, say, 60 per cent., which is a quite usual factor. The gas engine would save about half the coal, and with coal 70 per cent. of the cost the yearly saving would be $365 \times 24 \times .60 \times .35 \times .4$ equals $7.36 per kw. hr. produced. $7.36 capitalized at 15 per cent. for interest depreciation and fixed charges equals $49.00.

The gas engine plant would therefore be on a same footing as the $85.00 steam turbine plant assumed if the first cost of the gas engine plant were not more than $85.00 + 49.00 = 134.00. As the estimate of the first cost of the 16,000 B. H. P. gas engine plant per kw. capacity based on a capacity permitting 50 per cent. overload was only $118.94 it is seen that even looked at in its most disadvantageous light the gas engine plant in capitalized saving in operating expenses has a very considerable advantage over the steam plant in first cost.

Unfortunately for the gas engine its reputation has suffered at the hands of its supposed friends. Many miserable failures have been recorded, due generally to a desire to reduce cost of manufacture, and it is therefore but natural that the gas engine should for a time fail to receive the consideration its possibilities indicate it deserves.

It must be remembered that very little study of the gas engine in the central station has yet been made, particularly in relation to station economy. Possibilities like that suggested by Mr. H. G. Stott, Superintendent of Motive Power, Interborough Rapid Transit Co. N. Y., of using gas engines continuously at full load and taking care of the fluctuations in load by steam turbines are very promising. The use of the gas engine exhaust under boilers has already been tried with success abroad.

If the extensive adoption of storage batteries as suggested above may be expected for the purpose of evening the load on central stations; that is if batteries and their related machinery can be obtained, which in spite of enormous variations in external load will call on the main station for loads which will fluctuate but a few per cent., then the small overload capacity of the gas engine will be a largely lessened objection to its introduction and likely disappear altogether as an objection in the larger sized plants.

The large gas engine is rapidly winning its place among the prime movers of the day, and from the advantages it has to offer central stations its extensive adoption by them in the near future seems assured.

Boiler practice, except for the introduction of the superheater, has

changed less in the last six years than any other part of the power plant. Steam pressure as high as 175 lbs. were in use at the beginning of our century and the maximum is now 200 lbs. The maximum steam temperature obtained in this country is about 500° Fahr., not nearly as high as the maximum temperatures in use in Europe, and with this temperature no trouble whatever is experienced in steam turbines, nor, with a little care in the lubrication and packing, in the auxiliaries. The size boiler units generally used still varies from 500 to 650 H. P., but some exceptional units said to be of 1,000 H. P. capacity have been installed. It is now realized that the boiler room is the largest part of the modern plant, and that any further reduction in size of building and ground space must be effected in the features of the boiler room. Many of our designers seem to have gone to extremes to save ground space, even at the cost of sacrificing convenience of access and operation, and in spite of the fact that particularly with high tension transmission land is often cheap and many times a paying investment; but the indications are that larger boiler units may in the future be used as a method of decreasing first cost.

Automatic stokers are now almost universally used where soft coal is burned, and coal is as universally handled entirely by machinery. One large plant has a coaling station capable of removing 700 tons of coal an hour from barges.

Screwed steam piping and fittings have given way to superior constructions. Cast steel fittings are used almost universally, and the pipe flanges are either steel forgings into which the pipe is rolled or else forged directly on the pipe itself.

Switchboards have dwindled to control boards, operating the switches from a distance through electrical or pneumatic means.

The changes which have taken place inside the power-house since the beginning of our century have been as complete and probably more rapid and numerous than have been experienced at any time in the history of engineering.

The antiquated, though not old, stations of the last century seemed to be a gradual growth. Their different units installed at successive periods were often a tangible commentary on the history of the art of generation and distribution of electric power, and almost universally these units were intentionally an assorted lot of different sizes. While the art has not yet reached a definite state and its development is still advancing probably at fully as rapid a rate as has been experienced in the last six years, this century's demands for power have been so

great and come on us so quickly that we have rushing to completion stations of as much as 30,000 kw. capacity, and the stations themselves, instead of the units in them, may be taken to indicate the state of the art when they were planned. The different machines in the old stations used to be our units of study, thought, and comparison; now our units are whole stations. The central power plant of today is the subject of very careful engineering study and investigation, and has very properly come to be looked upon as a unit of itself—a complete machine designed to take coal in one end and deliver electric energy at the other.

DISCUSSION.

Chas. E. Lucke.—The subject of large power generators for the purpose of producing power at the lowest cost, in a central station, may be made, and has been with me, a subject of considerable study; and I have rather enlarged, as Mr. McBride did, on the gas engine phase of it, although I have never neglected the proper study of steam, oil, and water-power plants. I have gone rather deeply into the gas end of it, because I believe there are greater possibilities in that end and less good work done than in the others, and therefore greater opportunities for the men who would work hard. I have seen, from the time the gas engine began to be, about ten years ago, nearly every engine that has been built, both in America and Europe, and I have been closely connected with a good many of them; I know what they cost to build and to run, and a good many of their tricks and troubles; and that brings me directly to what I am sorry to have to make—a form of criticism of Mr. McBride's paper. He is entirely too optimistic. The gas engine is a mighty good machine in the right place and in the right hands. A gas engine power plant is assumed in this paper to cost $90.00 per kw. (page 169); I am rather afraid that if anyone seeks to buy one for that figure, he will be disappointed; it is too low. I know of plants that cost twice as much as that. Turning now to the cost of power generated by these plants (page 171), I find the cost of power also too low; approximately one-half of what it ought to be. Now it is unsatisfactory to enter into a detailed discussion of somebody else's paper, and I rather avoid it, but throw out the suggestion for investigation, that gas engine plants will cost nearer twice the figures given, and the cost of power will be nearer twice this figure of .245 cents per kw. hour than the figure itself.

Gas engines can be applied to central station work in any size in which they are built, if, first, the regulation is not required to be too close. In spite of all that has been said about the regulation I must confess the gas engine cannot regulate as good as the steam engine or the turbine. It can maintain a certain R. P. M. at a constant load just about as good, but it cannot reduce the momentary swing on a sudden load change to as small a value as a steam engine or a turbine. I went into that question in a recent paper before the Boston Section of the American Institute of Electrical Engineers. Direct current work ordinarily does not require closer regulation than the gas engine can give, but 60 cycle A. C. work is beyond it. Twenty-five cycle A. C. work can be handled, but 15 cycles can be

handled better because of certain inherent limitations in the cycle of the engine, regardless of how perfectly the mechanism may be designed.

Turning to the prior question of when it will be advisable to use the gas engine instead of the steam engine, and assuming that the conditions of regulation can be met equally well by both, the whole question boils down to two things: (1) cost of coal per ton; (2) load factor. When coal is expensive and the load factor high, it will be advisable to use gas engines, and they will earn good dividends on the increased first cost over a steam station. There is always an increase in first cost over the steam station. The gas engine station will always cost more, but the excess is justified if the load factor is high enough, thereby giving the benefit of continuous operation with corresponding reduction of the fuel charges, and if coal is costly enough. I would not think of recommending gas engines to anybody if coal can be bought for 60 cents a ton, as it is at some mines, because the increased first cost would not pay for itself. But if coal was $6.00 a ton, the situation is reversed if the load factor is high enough. The more I analyze this proposition, the more convinced I am that load factor and cost of coal will be the deciding elements.

Mr. McBride says, on page 171: "As no data have been obtained on maintenance cost of large gas engines and gas producers in 'central' station practice, it has been assumed that this will be the same as that of turbines, etc." Whether he means that *he* has not obtained it, I do not know, but it is in existence, not necessarily for "central" stations, but for aggregations of gas engines for any purpose. I recently gave some figures on this before the Electro-Chemical Society at the meeting of the New York Section. I am convinced that the maintenance cost of gas engine plants will always be higher than a corresponding steam plant. Perhaps I do not mean "always," but in the case of the present day designing of gas engines and producers, it will take a great deal of care to equalize the cost of these items, because the things that bring the repair bill up high are nearly always the little things involving more expense in time than in material, and which total up to a larger figure as a rule than for the steam stations.

H. P. Childs.—I would like to take exception to Professor Lucke's remarks on gas engines not being capable of operating 25 and 60 cycle alternators in parallel. Our company has, at the present time, a number of plants doing this most successfully. In our plants using our three-cylinder vertical type of engine, we use a quill coupling both for 25 and 60 cycle work. When we placed on the market our horizontal double-acting engine, we found it was not necessary to use the quill coupling for 25 cycle work, but we did believe we would have to use it for engines operating 60 cycle generators. We find, however, in a plant that we have installed at Hillburn, N. Y., that the engines run successfully with the quill couplings blocked so that they are inoperative. In the future, we will not use quill couplings on our horizontal engines. We have a 25 cycle gas engine plant at Warren, Pa., running a street railroad, and, as the grades are severe and the cars are very heavy, we get great fluctuations in load. The engines, however, handle the alternators with the same satisfaction as is obtained in the best steam plants. We are rather proud of our success in this particular line, and will be glad to demonstrate it to anybody who may be interested.

One of the independent operating companies at Hazleton, Pa., has a culm pile consisting of about 2,000,000 tons that has been stored up for a great many years.

This coal does not pay them to ship, so they have recently installed a plant to generate current directly at the mines. While this is just a starter, they expect to put in a large plant, and from careful engineering figures, the investment will pay handsome dividends. They have a large market for their power within thirty miles of Hazleton, and while they have no market for this culm, they are charging the culm to the plant at 50 cents per ton, so it enables their mining property to realize on what was heretofore practically a waste product and also make money on the electric plant.

On page 168 of Mr. McBride's paper, he mentions a number of plants that we have installed, giving the sizes of engines. I would like to make the following corrections and additions to this list:

WESTINGHOUSE ENGINES OF 500 H. P. AND UPWARD OPERATING, BEING ERECTED OR UNDER ORDER, AND RUNNING ON NATURAL, BLAST FURNACE, OIL, OR COKE OVEN GAS.

Name.	Location.	No. of Engines.	Total B. H. P. of Plant.
American Iron and Steel Co	Lebanon, Pa.	1	500
Atlantic Refining Co	Philadelphia.	4	2,000
Carnegie Steel Co	Bessemer, Pa.	2	4,400
Carnegie Technical Schools	Pittsburgh, Pa.	1	500
Fredonia Portland Cement	Fredonia, Kan.	2	1,100
Indiana Steel Co.	Gary, Ind.	8	20,000
Olean Street Rwy. Co	Olean, N. Y.	2	1,000
Union Traction Co	Independence, Kan.	2	1,100
Union Utility Co	Morgantown, W. Va.	1	500
Standard Steel Car Co	Butler, Pa.	1	500
Warren & Jamestown St. Rwy	Stoneham, Pa.	2	1,000
			32,600

Horizontal engines in operation, January 1, 1907, . . . 11,500 B. H. P.
Horizontal engines under order, . . . 32,070 B. H. P.

43,570 B. H. P.

WESTINGHOUSE PRODUCER GAS ENGINE AND PRODUCER PLANTS OF 500 B. H. P. AND UPWARD.

Name.	Location.	No. of Engines.	Total B. H. P. of Plant.
American Locomotive Co	Richmond, Va.	1	500
Atha Tool Works	Newark, N. J.	4	539
American Steel & Wire Co	Worcester, Mass.	1	800
Buenos Ayres Gt. So. & Gt. W. Ry.	Buenos Ayres, S. A.	11	2,315
Berlin Light Commission	Berlin, Canada.	5	710
Birmingham Small Arms Co	Birmingham, Eng.	3	750
Cadbury Brothers	Birmingham, Eng.	3	750
Consolidated Gas Co	Long Branch, N. J.	3	608
Gould Coupler Co	Depew, N. Y.	3	705
Great Western Ry	Swindon, Eng.	6	1,500
Hanson Gas & Elec. Co	S. Hanson, Mass.	3	680
London Paper Mills	Dartford, Eng.	4	1,000
London Northwestern Ry. Co	Camden Town, Eng.	7	920
Metropolitan Amal. Ry. Co	Birmingham, Eng.	3	705
Midland Railways	Heysham Harbor, Eng.	3	750

WESTINGHOUSE PRODUCER GAS ENGINE AND PRODUCER PLANTS OF 500 B. H. P. AND UPWARD (*Continued*).

Name.	Location.	No. of Engines.	Total B. H. P. of Plant.
Norton Emery Wheel Co.	Worcester, Mass.	1	500
Potosina Electric Co.	San Luis Potosi, Mexico.	8	1,537
Rochland Electric Co.	Hillburn, N. Y.	7	2,140
So. Staffordshire Mond Gas Co.	Dudley Port, Eng.	2	500
Sayles Bleacheries	Saylesville, R. I.	2	735
Tweedales & Smalley	Castleton, Eng.	2	500
Walthamstow Municipality	London, Eng.	13	2,300
Winchester Repeating Arms Co.	New Haven, Conn.	10	2,915

Wm. C. Kerr.—A few days ago our Mr. Head suggested that I might have something of interest to the Club, but, as stated at the time, I do not think we could have an intelligent talk without lantern slides to show the arrangement.

In reference to the exhaust steam turbines, I might state that the Philadelphia Rapid Transit Company installed at Mount Vernon Street Station, about fifteen months ago, two 800 kw. Curtis turbines of the D. C. type, operating on exhaust of Corliss engines which are running non-condensing.

Each turbine is operated on an 8,000 square foot Alberger surface condenser in connection with three Alberger cooling towers cooling the water for both condensers.

The two turbines, with the condensers, occupy two-thirds of one of the 1500 kw. engine foundations which was built for a future unit.

In regard to the operation, I can only state that the first has been in service since November, 1905, and they have been guaranteed to operate on forty pounds of exhaust steam per kw. hour, but we have never made any test to verify this, as we have always had an excess of exhaust steam. The steam is taken from the main exhaust line and no back pressure is used.

The only experiments we have made were to determine approximately the minimum load under which we could operate the turbine without drawing air back through the exhaust pipe. I am speaking only from memory, but so far as I know, these are about the conditions: We were carrying about 27 inches of vacuum and had a two engine load (1500 kw. each) on the station. One turbine was thrown in with the engines and took its full load from the engines without any decrease in vacuum. Then we tried the experiment with a one engine load and found that the turbine would take about half its load from the engine; then the vacuum fell to 24 inches, and we did not go beyond this point for fear of losing the vacuum on the turbine entirely.

At the time the turbines were installed, an estimate of the cost of the plant was made and showed that we could increase the output of the station without additional boiler capacity and get a fair return for the capital invested and the additional labor required.

Carl Hering.—Mr. McBride's paper contains much that is of interest. There are a few minor matters that I would like to comment upon. The rise of the alternating current system has been very much more gradual than he states; it is quite an old system; there were alternating current stations in Europe in the eighties, if I remember correctly. This system had a hard road to travel when it

was first introduced, and it may be interesting here to recall a little history. When the patents for the alternating current system were first brought to this country, the competing companies that were most adversely affected by it, recognized at once that the cost of transmission would be considerably lessened thereby, as compared with the cost of the direct current transmission, so they resorted, it was said, to inducing the New York Legislature to pass a law to kill criminals with the alternating current instead of hanging them, so as to give the impression to the public that this current was an exceedingly dangerous one, thereby creating a prejudice against it which would have to be overcome before it would be used to any great extent.

Mr. McBride says "As long ago as 1902," giving the impression that that was a very long time ago in the history of central stations. This makes some of us feel that we are getting old very fast.

He speaks of the cost of freight on coal, saying that the cost of transportation is about two-thirds of the whole cost of the coal to the consumer. In other words, for every dollar's worth of coal we burn, we pay two dollars for bringing it here. That would mean an efficiency of $33\frac{1}{3}$ per cent. in transmission. Now any electrical system that has so poor a transmission efficiency as that, would be considered very bad engineering, and yet we are to-day, so to speak, transmitting power in the form of carrying coal on railroads, with this extremely low efficiency. Moreover, the cost of the railroad with all its equipment is much greater than the cost of the electric plant to transport all that energy in the form of electric current, rather than to transport the coal on freight cars. In other words, the carrying of coal on freight cars is certainly a very poor and antiquated system at the present day, and it is surprising that it has continued to exist so long. There has been much talk about burning the coal at the mines and transmitting the electric power, but nothing seems to have been done in that direction, although it seems a tempting direction in which to work.

Mr. McBride speaks of 50,000 volts as though it were a small matter in electrical pressure, and favors going beyond that, even to 75,000 volts, as in one plant in California. While of course we all recognize the advantage of using high voltages on lines, yet it seems to me that when we get up as high as 50,000 and 75,000 volts, we are developing a whole lot of new sources of trouble, and I think the point will soon be reached, if it has not already been reached, when what might be called the cost of the danger involved would more than balance the saving in copper. With such voltages as 75,000, we begin to approach lightning on a small scale. I noticed a peculiar incident which showed that there was something going on in the air around these high tension lines at Niagara Falls. When the smoke from a locomotive was passing across these high tension lines, it formed into rings about the wires; this indicated to me that something was going on at a considerable distance from the wires which we may not fully understand.

Mr. McBride speaks of the Thury ststem, and gives the impression that this is new. It is quite old; it has been tried for many years, and does not seem to develop to any great extent. It seems to me that its chief sphere is in connection with a falling river that has a series of cataracts some distance apart. A central station can then be erected on each large fall, and all connected together. In that way it was used in Italy.

Although Mr. McBride speaks in the beginning of the paper very favorably of the

alternating current system, in the middle of the paper he says it is "far from ideal." One of the great drawbacks to it is the want of good motors, and a difficulty which will always probably adhere to it is that storage batteries cannot be used with it directly. Mr. McBride says that it is not at all unlikely that the near future may see the storage battery applied to strictly alternating current plants; he doubtless means indirectly, as it is at present.

In his table giving a list of some of the largest plants in this country, we, as Philadelphians, must regret that not a single one mentioned there is a Philadelphia station.

Mr. McBride has made the very common error of comparing pounds of steam with horse powers. Pounds of steam are units of energy, while horse powers are not; they represent power. This error is like comparing accelerations with velocities or velocities with distances. He says that one of the disadvantages of the gas engine is that its capacity for overload is only 15 per cent. It seems to me that this is largely a question of rating, and that if the makers did not rate them so high, the overload capacity would be greater. I do not quite see why he says that the starting of a large gas engine in "a minute or so" overcomes this objection. Are we really sure that a large gas engine can be started in a minute or so? My experience has been the reverse. The great trouble with the gas engine is that if you overload it, it will come to a dead stop, while the steam engine slows down and gives you warning.

While it is not to our credit, it may be of interest here to say that the three chief features of central stations with which the paper deals, as having produced good results, namely, the alternating current system, the steam turbine, and the gas engine, were all three brought here from Europe. They originated in Europe, although we in this country, I believe, deserve a certain amount of credit for having developed them to a greater extent than they were developed where they originated.

Henry H. Quimby.—We have heard so much of the proposition of generating power at the mines and carrying it to the cities instead of coal, that we wonder why it has not been done.

J. W. Ledoux.—It seems to me that one reason why power has not been transmitted from the mines is that fuel is only a small part of the cost; probably about one-half.

Emile G. Perrot.—The question just mentioned seems to be a live one. I would like to ask Mr. McBride if there have been any calculations made as to just how cheap power could be delivered in Philadelphia from power stations in the mining district, say Hazleton or Wilkesbarre. One thing occurred to me, and that is that we all have to have heat in winter time, and the natural way to generate that heat is, of course, to burn coal. Now would the cost of heating houses by electricity generated at the mines be any more than it would if the heat were generated in stoves or heaters?

H. K. Myers.—Of course figuring on the cost of fuel for gas producers, with the idea of getting down to about 1 pound per kw. hour, would mean 2,000 kw. from a net ton of coal; based on 10 per cent. loss with the transmission line would mean a charge of $2.00 per ton to get that fuel to its destination based on current at 1 cent per kw. hour, while the coal is now being shipped to Philadelphia at a much less price. Current is produced in Philadelphia after paying freight on coal

cheaper than it would be if it were transported over transmission lines from the mining centers.

Henry Leffmann.—In addition to the cost of transporting coal, the cost of removal of ashes must be taken into consideration. This is probably an item of considerable importance in large plants. So far as the railroad transportation of Pennsylvania anthracite is concerned, the freight charges are excessive, but the establishment of a system of supplying power directly from the mines would affect only the one class of freight. Indeed, by increasing the importance of the mines, by diversifying the industries at that point, the general freight business of the road might be increased. I would like to hear the problem further discussed. Coal differs much in quality. I have analyzed samples of anthracite which gave 45 per cent. of ash, other samples have fallen below 5 per cent. This loss in fuel is considerable.

W. S. Twining.—I note a statement in the paper to the effect that the two engines of 4000 H. P., started in 1901 in Brooklyn, were considered large units, and while the paper apparently deals exclusively with American practice, it might be well to call attention to the large units built by Ferranti for the Deptford Station in London in the early nineties. I believe the first units were 5000 H. P., and units of 10,000 H. P. were started, but I believe never completed or put in operation. It is worth noting that the large units did not develop except in connection with alternating current generators. For many years the limit of size for direct current machinery for either railway or lighting work did not go much beyond 1500 kw. The commutator of the direct current machinery was the limiting factor and the development of alternating current machinery and the successful development of the rotary converter made an immediate demand for large engines for direct connection. Another cause which brought about the development of the large unit was the equipping of elevated and underground roads with the multiple unit control which made large demands on the power house, so that until this was designed to correspond there was no equipment suitable for such service.

I also note that in the author's list of large plants, given on page 164, he has not made any distinction as to the portion of the plant which is engine-driven and the portion which is equipped with turbines. I also note that the writer has neglected the large stations in Philadelphia; of the Philadelphia Electric Company and the Philadelphia Rapid Transit Company. The latter alone contains 18,000 kw. of rated capacity in its present installation, the ultimate capacity being 50,000 kw.

I am very glad to see the table furnished the writer of the cost of the large sizes of gas engines. The figures given being less than $30 per B. H. P. for the gas engines is the first published estimate that I have seen of the cost of these large units, but the item of $5 per kilowatt for the station equipment, oil pumps, jacket water pumps, wiring, and switchboard, seems extraordinarily low, if this is to cover the switchboard for the generators, as this will run from $4 to $5 per kilowatt for high tension power house. Taken as a whole the estimate seems rather low, especially when it is compared with the cost of the average reciprocating engine plants as they have been built in later years.

James Christie.—The records of cost of electric current at the Pencoyd and Ambridge plants of the American Bridge Co. showed costs of six-tenths of a cent per kw. hour. The fuel cost is less at Ambridge than at Pencoyd, but other expenses were greater, and the totals averaged alike at both places. This cost

was made up of prices paid for all material and labor, etc., and to these were added 10 per cent. per annum of the entire cost of generating plant and the distributing lines, but did not include the losses at the lines, or it was the cost of current delivered at the switchboard. When to this cost was added the pro-rata of all the general distribution charges of the works, it made the entire cost of current very close to nine-tenths of a cent per kw. hour. These figures represented the costs for direct current electric stations not less then 1000 kw. capacity.

Thos. C. McBride.—Since reading the paper I have written the manufacturers of large gas engines in the United States in an endeavor to make up a list of the large engines now in operation in this country. I will take the liberty of adding to the paper some of the information three of these manufacturers have kindly sent me.

The Snow Steam Pump Works write that recent orders have increased the total of 50,450 H. P. stated in the paper to 66,850 H. P. in various stages of completion, and that they had in operation in this country up to February, 1907, in engines over 750 H. P. the following:

No. of Engines.	Power Cylinder Size.	Normal H. P. Each 15 Per Cent. Overload.	Type.
1	25 × 48	800	Single act. tandem vis-a-vis.
3	25 × 48	800	" " " "
2	38 × 60	4000	Double act. twin tandem.
3	22 × 48	1000	" " " "
1	22 × 48	1000	" " " "
3	22 × 48	1000	" " " "
4	22 × 48	1000	" " " "
3	22 × 48	1000	" " " "
1	22 × 36	840	" " " "
3	42 × 60	5400 maximum.	" " " "

From this list it is very evident that the Snow Steam Pump Works engine is well developed and that this concern deserves great credit for their pioneer work in the large gas engine in the United States.

The De La Vergne Machine Company refer to the Lackawanna Steel Works, Buffalo, N. Y., engines, in addition to which they have in operation about 4600 H. P. in engines of 600 H. P. and less. The Lackawanna engines are all two cycle, twin cylinder, double acting; the 8-1000 H. P. having cylinders $24\frac{3}{4}$ by $43\frac{3}{8}$ inches and the 16-2000 H. P. having cylinders $38\frac{1}{2}$ by 60 inches.

The Westinghouse Machine Company have very successfully started, since the writing of the paper, the two 2200 H. P. engines the paper stated were on order for the Carnegie Steel Company. These engines are of the same cylinder sizes as the larger Carnegie engine stated in the paper, the difference in power being due to difference in speed. The Westinghouse Machine Company report 11,500 B. H. P. in horizontal engines, mostly 500 H. P. capacity, in operation January 1, 1907, and 32,070 B. H. P. of horizontal engines under order.

It has been suggested, both by Mr. Twining and Professor Lucke, that the estimate of first cost is too low. The estimate of first cost used is based on actual selling prices received from manufacturers. Professor Lucke's thought that the plant would cost twice as much is probably based on the consideration of smaller sized units than have been selected for the proposed gas engine plant. The 4000

B. H. P. engines proposed are of a size approximating closely a large number of engines which have been and are being built, and there is no reason why manufacturers should not know exactly what they cost to build.

As to the cost of power calculated for the proposed plant it must be remembered that the figures given only cover certain items in the cost of power, these items being stated in the calculation. The "cost of operation" has been conservatively figured in its fuel costs and more and higher priced labor provided for than will be found necessary in many classes of services and localities, and I am disappointed that Professor Lucke, in stating that this figure is only half what it ought to be, has neither given any reasons for his criticism nor pointed to any parts of the estimate he may have thought in error. I cannot agree with Professor Lucke's view that 60 cycle alternating work is beyond the gas engine, first, because 60 cycle parallel operation with large gas engines is already an accomplished fact, and secondly, because there is no reason why the modern American twin tandem four cycle gas engine, with load curves usual in large plants, should not do as well with 60 cycles as a cross compound steam engine, and it must certainly be conceded that the latter will successfully operate modern generators.

The statement that "no data have been obtained on maintenance cost of large gas engines and gas producers in central station practice" has been commented upon. Professor Lucke, in his discussion, by stating that these data "are in existence" but "not necessarily for 'central' stations," has failed to distinguish between the "central" and the "isolated" station; two different classes of stations not only most likely doing work of a widely different character but also having organizations with different traditions and methods, all affecting the relative cost of operation. I am pleased that Professor Lucke partly confirms my opinion that the maintenance cost of the gas engine producer plant will not be more than that of the steam engine plant in that while he has stated the former will be the higher, he lays this condition of affairs to "present day designing of gas engines and producers." I cannot see why gas engines properly designed and built for conditions in this country should cost much if any more to maintain than steam engines and condensers, and there is no reason why producers, particularly of large sizes, should not be maintained at much less cost than boilers and high-pressure steam piping.

I am glad Mr. Hering has stated his views on some of the electrical features of the paper, but regret that neither he nor any of our electrical friends have offered any discussion of the recent developments in the storage battery briefly noted in the paper. Mr. Hering and others have spoken of the project of generation of electric energy at the coal fields and transmitting the power instead of hauling the coal. The paper spoke briefly of this project, and estimated roughly the relative cost of power at the two points.

Mr. Hering has criticized the gas engine for its lack of overload capacity and suggested that it be more conservatively rated. It must be remembered that the nominal rated capacity of any gas engine is determined more by the load at which it will run with best economy than by its ultimate capacity, just as is the case with a steam engine or a steam turbine. Fortunately for the steam engine and steam turbine the load corresponding to best economy is much less than, maybe only half, the ultimate capacity, but the margin is much less with the gas engine because maximum economy of operation is obtained with loads quite close to

the ultimate capacity. The statement of the paper to the effect that the small overload capacity of the gas engine was not a serious objection because the gas engine can be started in a minute or so was based on the thought that additional units could be thrown in very quickly, as the load on any station might be found climbing up, possibly more rapidly than usual, say, in the case of a lighting station at the coming on of a sudden storm. It is only too true that gas engines have had an unenviable reputation for difficulty and delays in starting, but modern engines, with their arrangement to run a few starting revolutions on compressed air taken from storage tanks, are now found to give no trouble. The Philadelphia High-pressure Fire Service Pumping Station at Delaware Ave. and Race St. has engines equipped for starting with air and illustrates well the ease with which gas engines can now be started and put under full load "in a minute or so."

I wish to thank you, gentlemen, for your kind interest in the paper, particularly Professor Lucke, who has come over from New York to be with us tonight.

PAPER NO. 1034.

SINGLE PHASE RAILWAYS.

F. E. WYNNE.

Read February 2, 1907.

MOTOR.

Electrical.—The single phase motor is of the series type; that is, the same current passes through the field and armature windings. Its operation on alternating current depends on the same principle which makes it operate on direct current. The armature of the motor may be considered as a single coil between brushes. The brushes are so placed that this coil has the maximum torque. The direction of rotation depends upon the relative direction of the magnetic field and the current in the armature. When alternating current is applied to the motor the direction of field magnetism changes each time the direction of current changes, consequently with fixed relation between field and armature windings the rotation is always in the same direction on alternating current as well as on direct current.

In adapting the series motor to alternating current operation certain difficulties were encountered which are not present in the operation of a series motor on direct current. In the coils which are short-circuited by the brushes, the alternating field magnetism induces a local current which may be comparatively large, the action being similar to that of a transformer. As the armature revolves the short-circuit currents are broken every time a commutator bar passes from under a brush, and this produces more or less sparking at the brushes. In order to overcome this sparking, preventive leads are inserted in the armature circuits between the commutator bars and the main coils, thus introducing additional resistance into the short-circuited portions of the armature and consequently reducing the short-circuit current. These preventive leads are proportioned to minimize the armature copper losses.

The power factor of the single phase motor is less than unity because of the self-induction of the field and armature windings. It is advisable to keep the power factor as near unity as possible, for additional current must be supplied for a given amount of actual work when the power factor is low. The self-induction of the field cannot be

entirely done away with, but it may be reduced by using a weak field. The effect of using the weak field is to reduce the air gap of the motor and the number of turns in the field coils.

The self-induction of the armature is additive to the self-induction of the field, thus tending to lower the power factor of the motor. However, it is not an unavoidable adjunct of any feature necessary to the operation of the motor. This self-induction of the armature is neutralized by the auxiliary or compensating winding which is connected in series with the other motor windings, and is so disposed that its resultant magnetic field is directly opposed to and equal in amount to the magnetic field due to the armature's self-induction. This neutralization of the armature self-induction decreases the total self-induction of the motor and thus raises the power factor above what it would be without the neutralizing winding.

The series motor, whether direct current or single phase, is particularly suited to traction work because of its characteristics. At heavy loads the speed is low and the tractive effort large. At light loads the speed is comparatively high and the tractive effort low. One result of these characteristics is that when starting with a given acceleration the motor is running at full voltage sooner than would be the case with a constant speed motor, and so is subject to control losses for a shorter period, thus reducing the power consumption. In addition to this, the speed of the motor accommodates itself to the profile of the road, running slower on grades, where a large amount of tractive effort is required, and speeding up on the level, where the necessary tractive effort is small. The result of this characteristic is to somewhat equalize the horsepower drawn from the line under varying conditions and to minimize the heavy loads drawn from the line in ascending grades or starting.

The speed curve of single phase series motors is somewhat steeper than that of the direct current motor of the same capacity. In series motors the torque is a function of the current, the torque with alternating current being slightly less than with the same direct current and same arrangement of fields, chiefly because of the decrease in the effective value of the field magnetism with alternating current, and partly because of the demagnetizing effect of the short-circuit current. The torque in starting with a given current is practically the same as when running with the same current, and consequently the single phase series motor is not subject to the difficulty which is present in starting single phase induction motors and no special arrange-

ment of winding is necessary for obtaining all the starting torque desired.

In the matter of efficiency, the single phase motor is from 3 percent to 5 percent less efficient than the equivalent direct current motor. It will be seen later that this is not a serious matter, because of the reduced losses in other parts of the system when operating single phase.

The ease and efficiency with which the voltage of alternating current may be changed by means of a transformer on the car make it possible to design the motors for comparatively low voltage without regard to what trolley voltage may be desirable in a particular case. The use of a multiple circuit winding on motors above 50 horsepower balances the magnetic pull on the armature even when it is slightly out of center. The single phase motor will stand some kinds of abuse without experiencing the bad results which such treatment would bring to direct current motors; for instance, the brushes may be grounded or short-circuited without producing bucking or flashing, and full voltage may be applied directly to the motor at standstill. Over against these advantages there is the disadvantage that when stalled the motor cannot be subjected to a heavy current for so great a time as could a direct current motor without danger of injury to the preventive leads. This is not a matter of great importance, however, as intelligent operators will not subject their motors to such treatment whether they be operating single phase or direct current equipments.

Mechanical.—Mechanically, the motor is of the box type. The field is laminated and held in a solid steel shell. It is built with inwardly projecting poles, around which the strap-wound main field coils are placed, as in the direct current motor. The pole faces are slotted for the reception of the neutralizing winding, which resembles in appearance the stator winding of an induction motor.

The armature is similar to a direct current armature in general construction and is strap-wound for capacities above 50 horsepower. The regular armature winding is connected to the commutator bars through the preventive leads, instead of directly, as is the case with D. C. motors. The arrangement of the preventive leads is such that two leads are in circuit with each short-circuited coil where a proportionately high resistance is required to reduce the short-circuit current, and yet only two leads are in the circuit between adjacent brushes where a comparatively low resistance is desirable in order to reduce the C_2R loss due to the working current.

The commutator is similar to the direct current commutator, but

is somewhat larger. To reduce the voltage induced by transformer action upon the short-circuited coils, the armature winding has a single turn per coil and a larger number of coils per circuit than a similar D. C. motor. Consequently the commutator has a relatively large number of bars. In operation perfect commutation is obtained and the commutators take a good polish. Where sparking has occurred with excessive overloads or due to improper adjustment of the brushes, it has been found to be less destructive than direct current sparking.

The brush holders are of the sliding shunt type and are supported by babbitted seats on the frame. The use of multiple circuit windings necessitates supplying one set of brushes per pole. The low voltage used gives comparatively large current, which necessitates increased brush capacity.

The bearings are similar to those supplied with modern direct current motors and oil and waste lubrication has proved altogether satisfactory.

A single phase motor will weigh more than the equivalent direct current motor. This is largely because the shell is magnetically idle. It is also somewhat more expensive to build.

The refinements in the design of the series motor which adapt it to operation on alternating current result in making it an improved D. C. motor. Its operation from direct current is, however, somewhat more severe than for a similar direct current motor, because of the greater insulation strains due to the fact that the field discharge is more severe with laminated field poles than with solid field poles. The torque on direct current is somewhat higher than on alternating current. Equipments which are to operate on both A. C. and D. C. may be arranged to operate on A. C. with the fields in multiple. This enables a suitable speed for direct current city work to be obtained by operating at reduced voltage with the fields in multiple, and a speed suitable for D. C. suburban operation may be obtained by utilizing full voltage with the fields in series.

The satisfactory operation of the motor just described has made possible the use of the single phase system of railway operation with its attendant advantages.

Control.

General.—The purpose of control apparatus is to supply power from the contact line to the motors as required by operating condi-

tions, and to do this in a way which is practically the most economical, the least productive of large mechanical strains in the equipment, and the most comfortable to passengers. Single phase control also provides for the collection of power at high voltage and its application to the motors at low voltage.

The ideal control takes power from the contact line in proportion to the work being done by the motors. For starting from rest a definite voltage is required at the motor terminals. To increase speed an increase in the applied voltage is necessary. By means of the car transformer the voltage may be applied to the motors as required and power taken from the line in proportion to the work being done.

This method of control avoids rheostatic losses, and by making the successive increments of voltage sufficiently small an acceleration of any degree of uniformity may be attained. The choking effect of the apparatus on alternating current makes it possible to get a very smooth acceleration with few notches on the controller, usually about one-half of the number required with D. C. equipments.

Hand controllers are satisfactory for equipments aggregating 300 horsepower or less, and do not require magnetic blowouts to prevent injury to the contacts. With single phase equipments multiple unit control becomes simpler than for D. C., because it is not necessary to provide for series parallel connections. Direct current has usually only two, and at most only three, efficient running speeds, which are fixed by the line voltage and load and are beyond the motorman's control. Single phase control may be arranged so that each notch is an efficient running point, and thus give the motorman more complete control over his car and provide for more efficient operation under varying conditions. A high voltage tap may be provided for making up lost time or supplying normal voltage to the motor when the voltage of the contact line is low. This provision is not possible with direct current.

Apparatus.—The change from high to low voltage is accomplished by means of an auto-transformer on the car. This transformer has a single winding, one end of which is connected permanently to the ground and the other end to the collector through a fuse or circuit breaker. Speed control of the motor depends upon the voltage control. For supplying the various voltages, taps are brought out from the transformer winding at points to provide the desired voltages. In addition to supplying reduced voltage efficiently to the

motors, the auto-transformer supplies power for the compressor motor and light circuit and protects the car equipment against lightning and line disturbances. This, in connection with the lightning protection provided for the contact line, makes it unnecessary to use lightning arresters on the cars themselves. On locomotives or car equipments using forced ventilation, air-blast transformers are used. Otherwise the transformer is of the oil-insulated self-cooling type.

In order to avoid opening the entire motor circuit when going from point to point in the process of starting up the car, and to do so without short-circuiting part of the transformer winding, a pre-

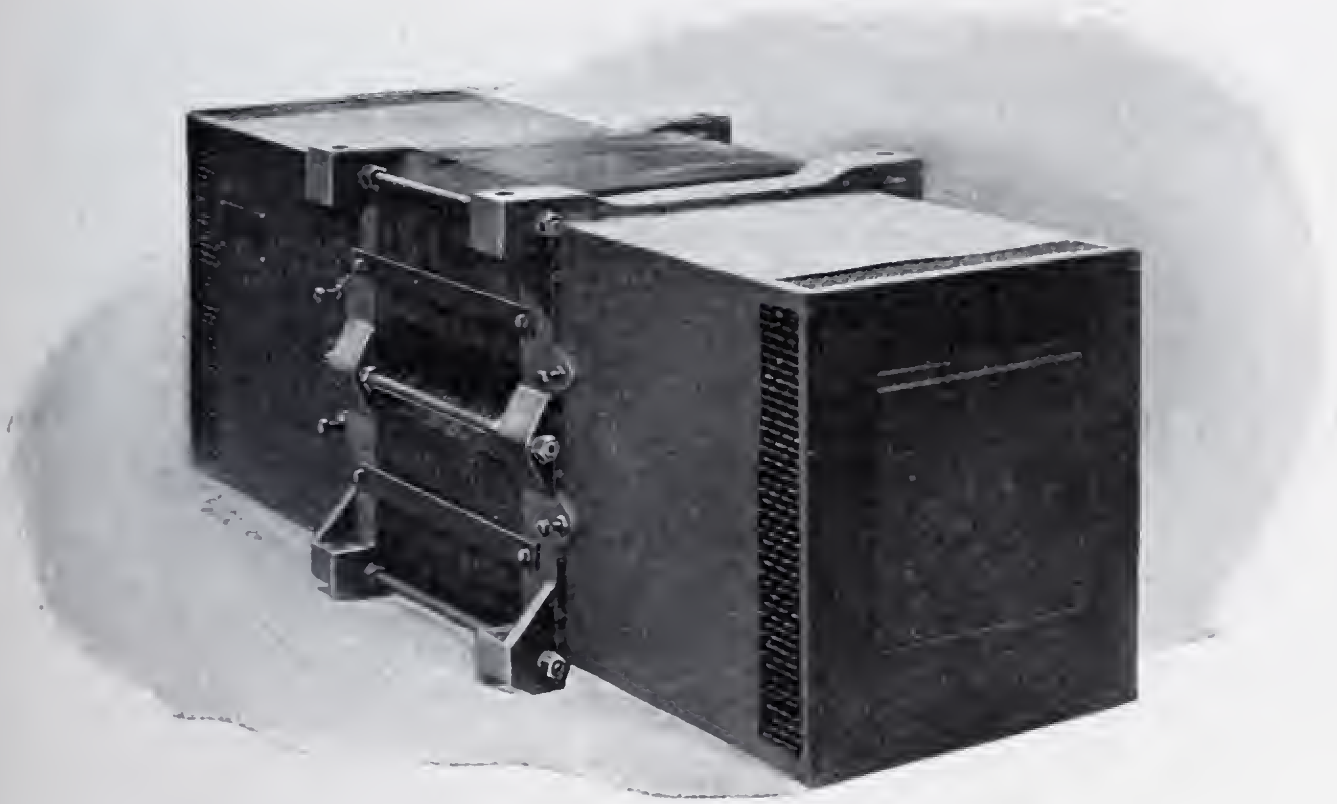


FIG. 1.—AUTO-TRANSFORMER.

ventive coil is used. This is simply a low resistance coil wound around an iron core so that the coil is highly inductive. The terminals of this preventive coil are connected to the several taps of the transformer winding by means of the controller, and the connection to the motor terminals is made from the middle point of the preventive coil. This arrangement avoids any excessive drop in the preventive coil and at the same time bridges a certain portion of the transformer winding without short-circuiting the same. The terminals of the coil are alternately detached from the transformer taps and connected to higher taps. With the larger equipments groups of from three to five preventive coils are used.

When hand controllers are used for operation on A. C. only a preventive resistance is supplied to give a cushioning effect in notching up and to prevent destructive arcing at controller contacts without having recourse to the magnetic blowout coil common to D. C. controllers. The single phase hand controller is similar to a direct current controller, except that fewer points are provided and all points may be made running points. With equipments for hand control canopy switches are provided in the trolley circuit.

With equipments exceeding 300 horsepower total capacity and for train control, the unit switch system of control is always used

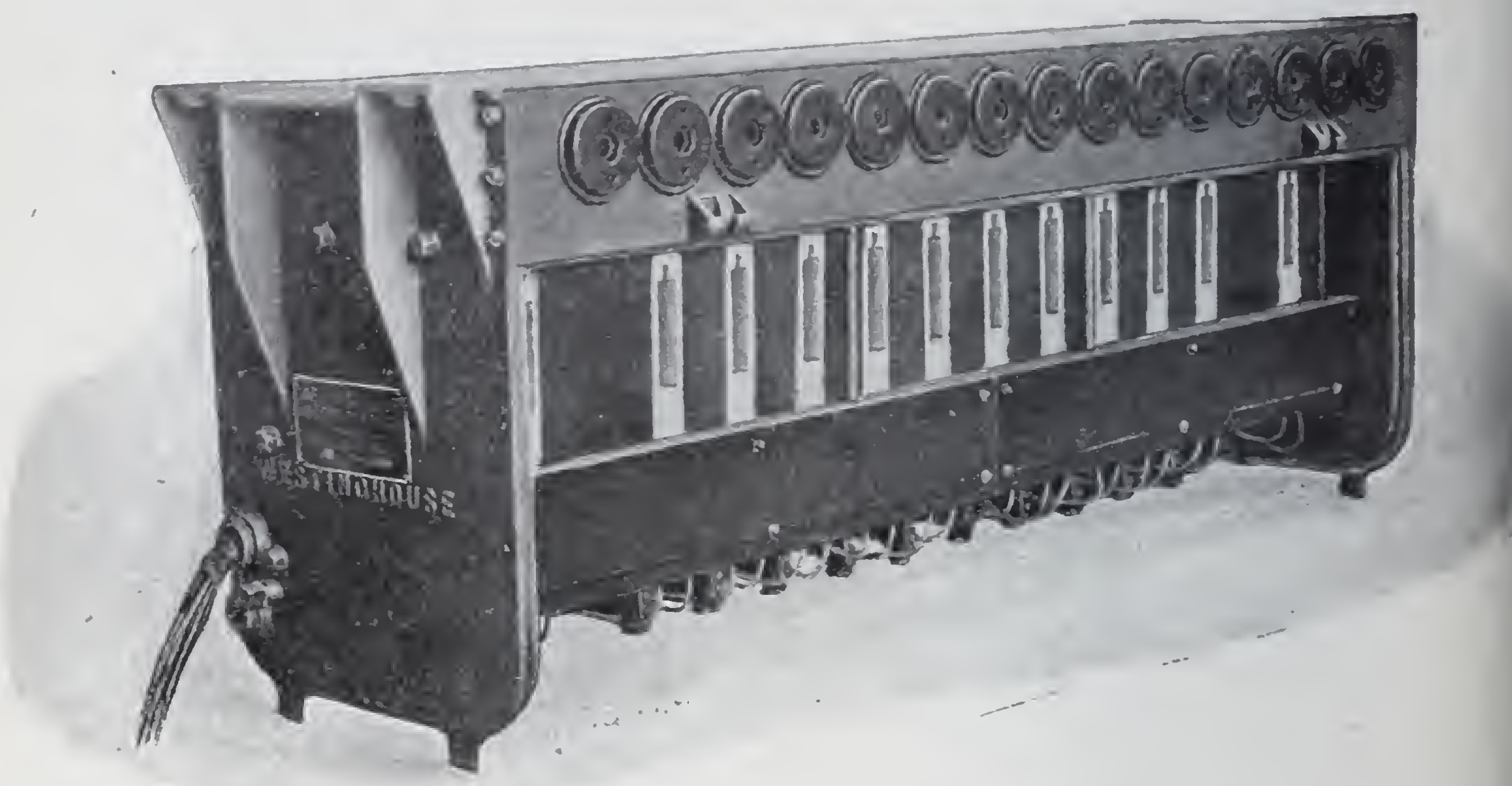


FIG. 2.—UNIT SWITCH GROUP.

and is similar to the D. C. unit switch system. Of course, it may be used on the smaller equipments also.

The place of the main drum of the hand controller is taken by the unit switch group, which consists of a number of individual switches electro-pneumatically operated. Each of these switches is provided with its arcing box and magnetic blowout. This, together with the quick positive action of the switch, makes it unnecessary to provide a preventive resistance. The switch group is assembled in a form which is at once accessible, compact, and well protected.

For operating the unit switches which are in the power circuits a secondary control system is provided. This consists of a storage

battery for supplying current to the control magnets, and a master controller for making the necessary contacts in the secondary circuit. By means of a system of interlocks provision is made for the proper sequence of switches. Automatic acceleration may be provided for, and thus the amount of current drawn from the line in starting predetermined and made independent of the motorman. When automatic acceleration is used the motorman can still operate his car at any of the reduced voltages obtained in coming up to full voltage, by moving the master controller handle back one point at the proper time, which prevents further progress of the unit switches.

FIG. 3.—MASTER CONTROLLER.

The reverser is of the air-operated drum type and performs the function of the reverse drum in the platform controller, making the connections between motor armatures and fields which determine the direction of motion of the car.

A small motor-generator set may be provided for charging the battery with direct current. Aside from the strictly electrical apparatus required for the unit switch control, it is necessary to provide a set of air apparatus for supplying compressed air to the cylinders which operate the main control apparatus. This set of air apparatus comprises an auxiliary reservoir, check valves, reducing valves, cocks, etc.

In addition to the apparatus which is necessary for operating on A. C. alone, it is necessary to provide certain other items if operation by direct current is desired. For collecting direct current, wheel trolleys must be provided, and these should be supplied with insulated bases and an emergency switch for connecting the A. C. circuits to the wheel trolleys in case of accident to the pantagraph trolley on A. C.

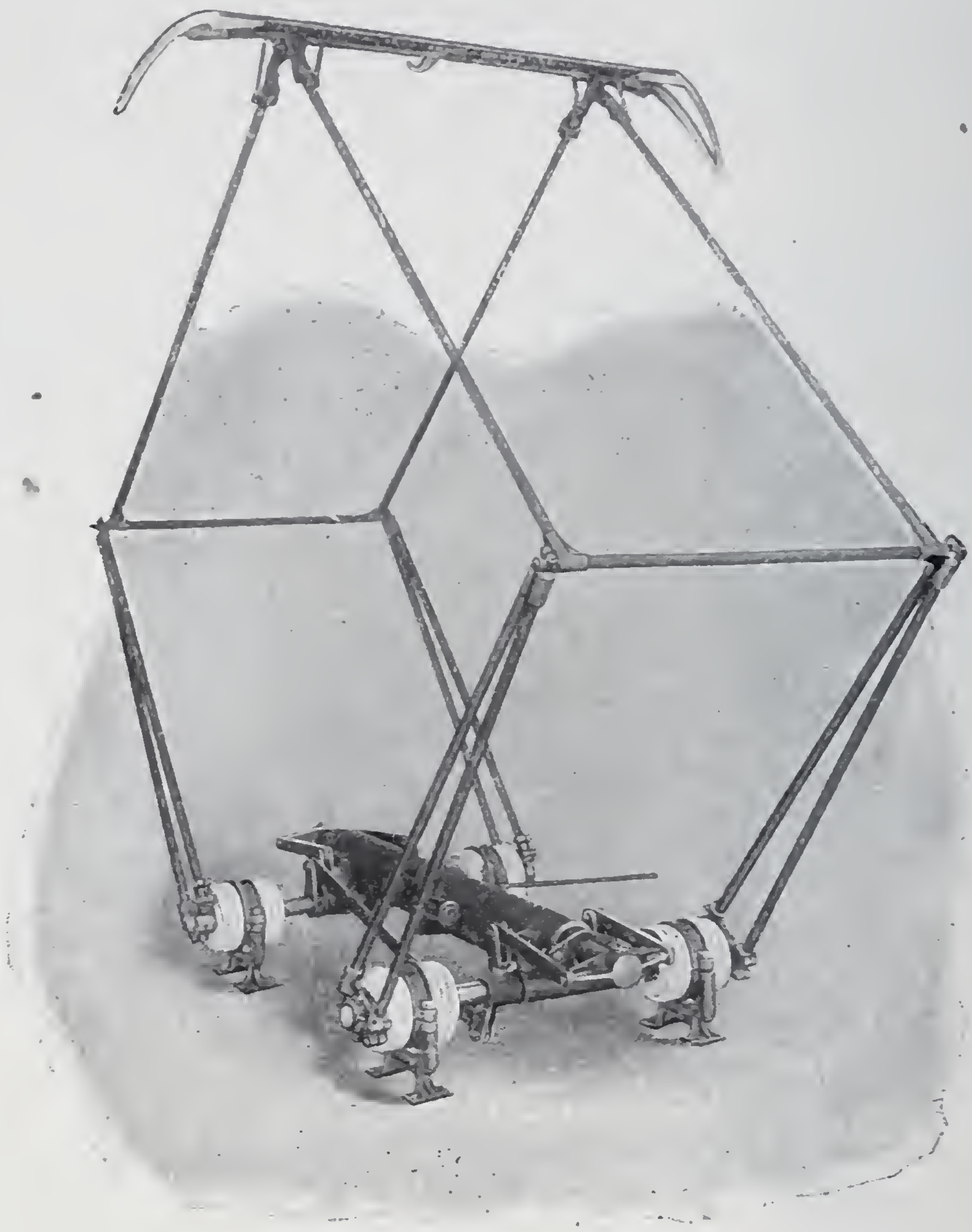


Fig. 4.—Pantagraph Trolley—Raised.

For hand control, the platform controller contains extra drums and magnetic blowout for the D. C. service and is consequently much heavier than a simple A. C. platform controller. The remainder of the extra apparatus for hand control consists of a direct current fuse box, a D. C. lightning arrester, and a set of diverters for use on direct current.

To adapt unit switch control for A. C. and D. C. operation, the additional apparatus not previously described consists of a line switch in the D. C. circuit, a change-over switch and relays for operating the same, plug cutouts for disconnecting the line switch when operating on A. C., and a battery-charging resistance to be placed in series with the battery so that it may be charged from the direct current supply circuit.

A. C. control is in itself very efficient, the losses in the control system usually running about 5 percent of the power input to the motors. However, in interurban service these losses, together with the lower efficiency of the single phase motor and greater weight of equipment,

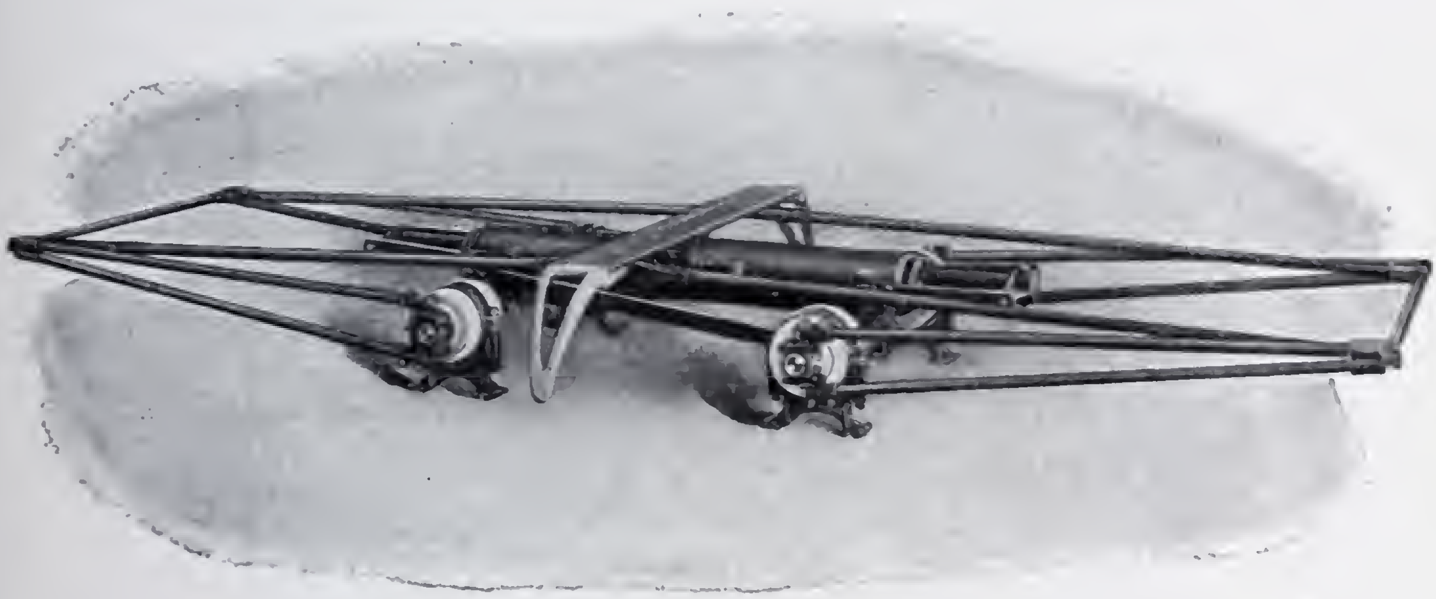


Fig. 5.—Pantagraph Trolley—Lowered.

about balance up the saving obtained by avoiding rheostatic losses, so that the power consumption at the car is practically the same for the two systems. Although the A. C.-D. C. operation of single phase equipments is perfectly practicable, the equipments are handicapped in such operation by the extra complication and weight of control. Consequently it would seem advisable to avoid operation from direct current systems wherever possible.

Collector.

The wheel trolley is a very good current collector for low and moderate speeds, but possesses an evil tendency to leave the wire at high speeds and do more or less damage to the trolley construction. When such trolleys are used with the single phase system they should be

mounted on insulated bases because of the comparatively high voltage used on the contact line. The limit of voltage for wheel trolleys is as yet undetermined, but their adaptability to medium voltage service at moderate speeds is fully proved by the fact that they are operating successfully at 1500 volts on the system of the Westmore-

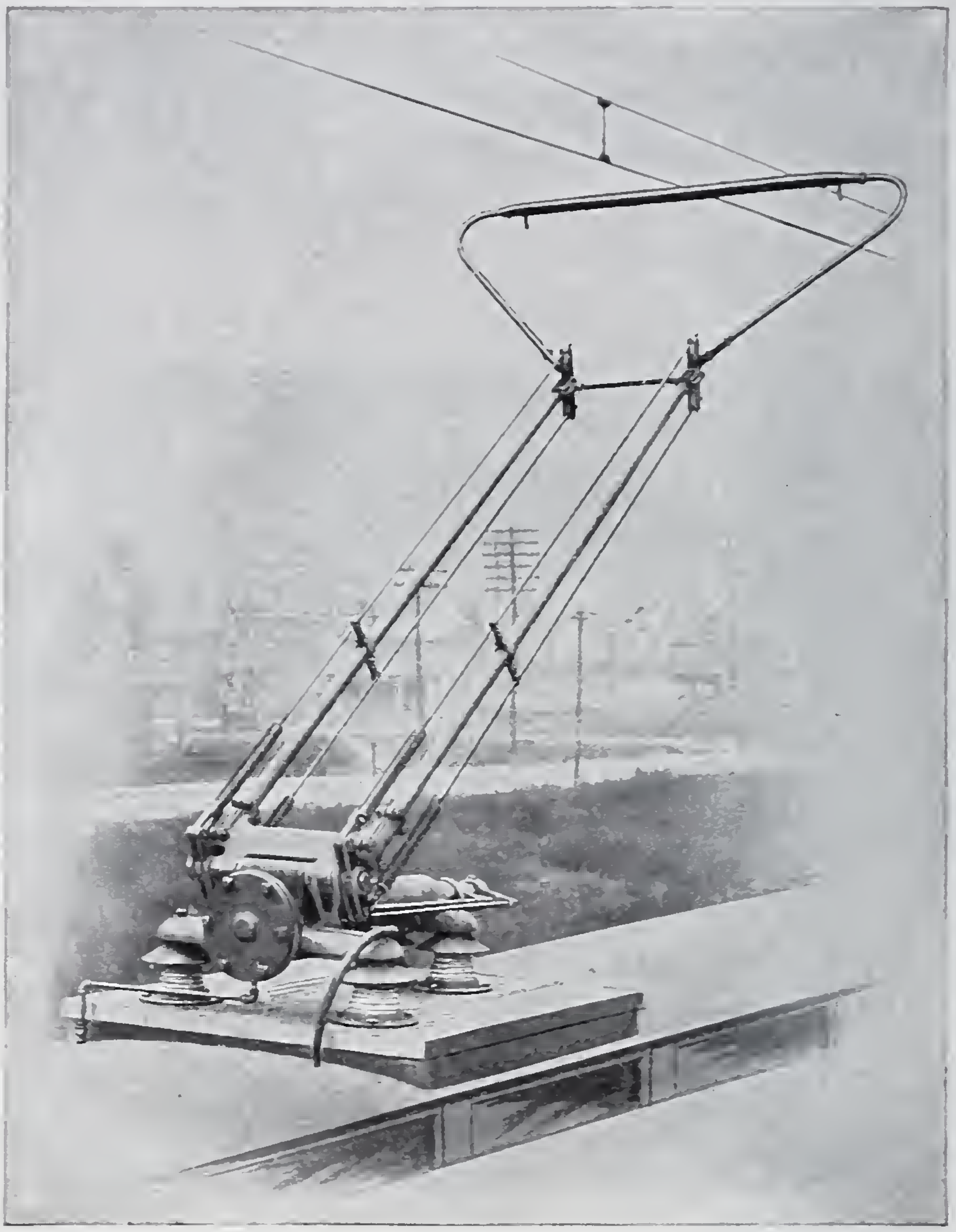


Fig. 6.—Bow Trolley.

land County Railway and at 2200 volts on the Atlanta Northern Railway and the Long Island Railway.

For high speeds it is advisable to employ a sliding contact for current collection. For alternating current operation the third rail and its sliding shoes are out of the question, except in very special cases, because single phase operation almost invariably implies high voltage on the contact line, which is not compatible with a third-rail installa-

tion. To collect current from an overhead trolley line the bow and pantagraph trolleys are equally successful. The form of these trolleys is such that they will not leave the wire. Distribution of wear over the surface of the contact plate is effected by staggering the trolley wire. The contact plate is located in the center of the trolley and is removable, so that it may be easily renewed. Results which have been obtained show that the sliding contacts wear at least as well as wheels, for average service having a life of about 5000 miles. Friction between the trolley and wire is reduced by the use of a lubricant placed in two longitudinal grooves in the contact surface of the bow. The wear on the trolley wire is inappreciable. With a sliding collector the car's direction of motion may be reversed without making any changes in the position of the trolley. The bow and pantagraph trolleys are not capable of collecting as heavy currents as wheel trolleys, but this cannot be classed as a disadvantage, because with high voltage the current to be collected is comparatively small, and so great a collecting capacity is not needed as with D. C. The use of such a trolley also removes one of the great objections to overhead work in yards and terminals.

COMPARATIVE CONTROL SCHEDULES FOR QUADRUPLE EQUIPMENT OF 50 HORSEPOWER SINGLE PHASE MOTORS.

A. C. Only.

For Trolley Pressure up to 6600 Volts.

Hand Control.	U. S. Control.
1 pantagraph trolley.	1 pantagraph trolley.
2 platform controllers.	2 master controllers.
2 canopy switches.	1 switch group.
1 atro-transformer.	1 auto-transformer.
1 preventive coil.	1 preventive coil.
1 preventive resistance.	
1 set wiring.	1 set wiring.
1 fuse and fuse block.	1 fuse and fuse block.
1 set lighting details.	1 set lighting details.
	1 reverser.
	3 junction boxes.
	2 receptacles.
	1 jumper.
	1 storage battery.
	2 S. P., D. T. knife switches.
	1 set air apparatus.
Weight = 4745 lb.	Weight = 4900 lb.

COMPARATIVE CONTROL SCHEDULES FOR QUADRUPLE EQUIPMENT OF 50 H. P. SINGLE PHASE MOTORS.

A. C. and D. C.

For Trolley Pressure up to 6600 Volts A. C. and 650 Volts D. C.

Hand Control.	U. S. Control.
1 pantagraph trolley.	1 pantagraph trolley.
2 No. 6 trolleys with insulated bases.	2 No. 6 trolleys with insulated bases.
2 platform controllers.	2 master controllers.
2 canopy switches.	1 line switch.
1 D. C. lightning arrester.	1 D. C. lightning arrester.
1 emergency switch.	1 emergency switch.
2 fuse boxes.	2 fuse boxes.
1 auto-transformer.	1 auto-transformer.
1 set diverters.	1 set diverters.
1 set wiring.	1 set wiring.
1 set lighting details.	1 set lighting details.
	2 switch groups.
	1 reverser.
	3 junction boxes.
	1 changeover switch.
	2 receptacles.
	1 jumper.
	3 relays.
	2 plug cutouts.
	2 storage batteries.
	1 preventive coil.
	2 D. P., D. T. knife switches.
	1 set air apparatus.
Weight = 6580 ℔.	Weight = 6715 ℔.

Trolley Line.

As has been previously stated, the ease and efficiency of voltage transformation on the car makes possible the use of high voltage contact lines. To this one item may be attributed a large proportion of the saving in first cost which may be obtained in many cases by the use of a single phase system. The direct result of the adoption of high voltage is to cut down the current capacity of the contact line and make possible the use of an overhead trolley line as against third-rail construction, even for heavy service. The trolley has the advantage of greater flexibility for extensions, and by proper construction may be made to give greater reliability and safety than the ordinary direct current trolley line. The chief requirement of the trolley line is that it shall be mechanically reliable, and this is a good requirement for direct current as well as single phase, often justfying the extra cost of catenary construction, without taking into consideration the question of high voltage.

A typical catenary trolley construction which has been developed consists of a 000 groved trolley wire supported from a $\frac{7}{16}$ inch stranded steel messenger cable by rigid hangers spaced at intervals of ten feet. The messenger cable is permitted to sag and several lengths of hangers are used, so that the trolley wire is maintained in a position parallel to the track. This construction is very rigid, permits of but small motion, gives a great degree of safety, and facilitates current collection,

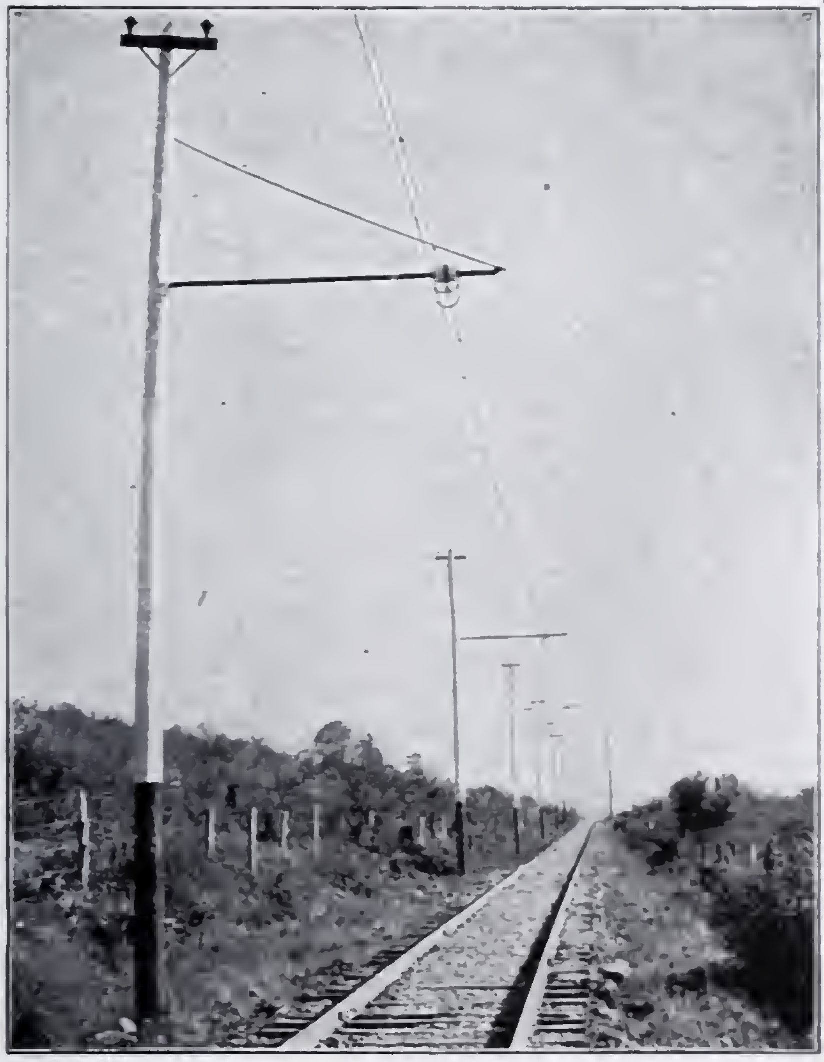


FIG. 7.—CATENARY ON STRAIGHT TRACK.

especially at high speed. The messenger wire is supported by clamps around insulators cemented to malleable iron sleeves which are slipped over the bracket arms. Where wheel trolleys are used the insulators are protected against damage due to the trolley leaving the wire by stirrups on either side. These stirrups pass under the messenger wire and thus serve to catch the messenger wire and prevent its falling to the ground in case it becomes detached from the supporting clamp. Lightning arresters are located at intervals along the line and section

breaks are usually inserted in the trolley immediately in front of the feeding points.

For single track roads side bracket construction will usually be found satisfactory. Where it is necessary or desirable to use cross-span construction the span wire takes the form of a catenary with the hori-

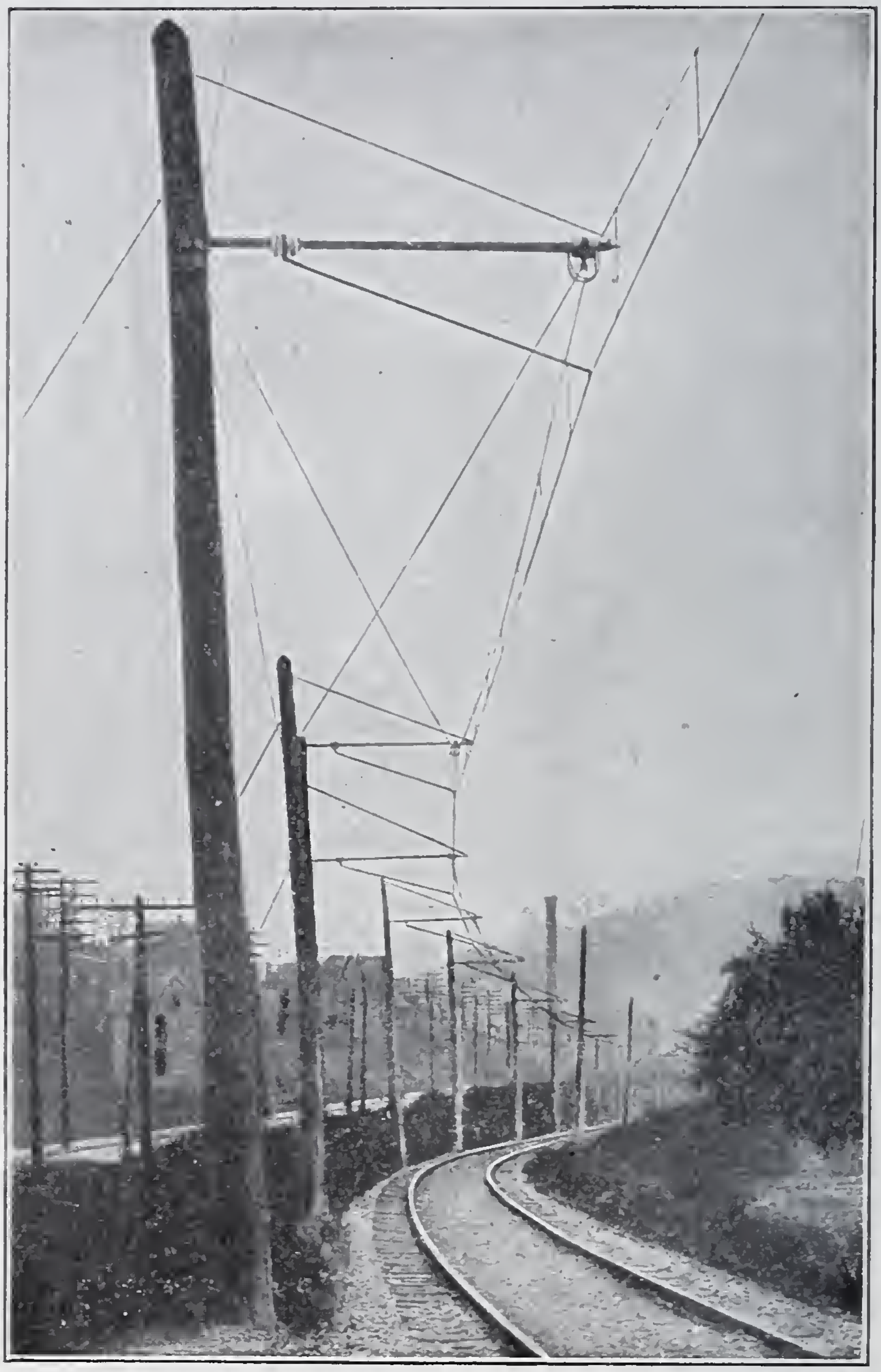


Fig. 8.—Catenary on Curve.

zontal wire above and the sagging wire below. The latter takes all the strain. In this case the insulators are placed next to the poles. Such construction is suitable for double track roads also. On new double track roads where the track centers may be spaced to give the proper clearances, center pole construction is good practice.

For steam road electrification, where there is extra heavy service

with a large number of tracks to be electrified, a form of double catenary and latticed steel bridge supports has been devised. In this case two messenger wires are used for each trolley, the three wires being connected together by rigid triangles instead of single hangers. Of course, such construction is comparatively expensive, but in certain cases it is justified by the increased reliability and the increased length of span. Where steam trains are to be operated under an electrified section of road the trolley wire should be at least 22 feet

FIG. 9.—CATENARY AT TURN-OUT.

above the top of the rails. This height gives four feet clearance to a six-foot man on the top of a 12-foot car. Ordinarily the cars should be protected against danger from fallen trolley wire by a grounded metal covering on the roof, sheet copper being preferable for this purpose. In Europe this protection takes the form of grounded metal guards spanning the roof at intervals.

The successful operation of this form of catenary at pressures up to 6600 volts is a matter of record. With stronger insulation there

is no reason why it should not be perfectly reliable and safe at pressures up to 22,000 volts. In Sweden 18,000 volts trolley pressure has already been used. The impedance of a 000 copper trolley with $\frac{7}{16}$ inch messenger to 25 cycle current is equivalent to that of a 0000 copper conductor.

With direct current the drop in trolley, feeders, and track may

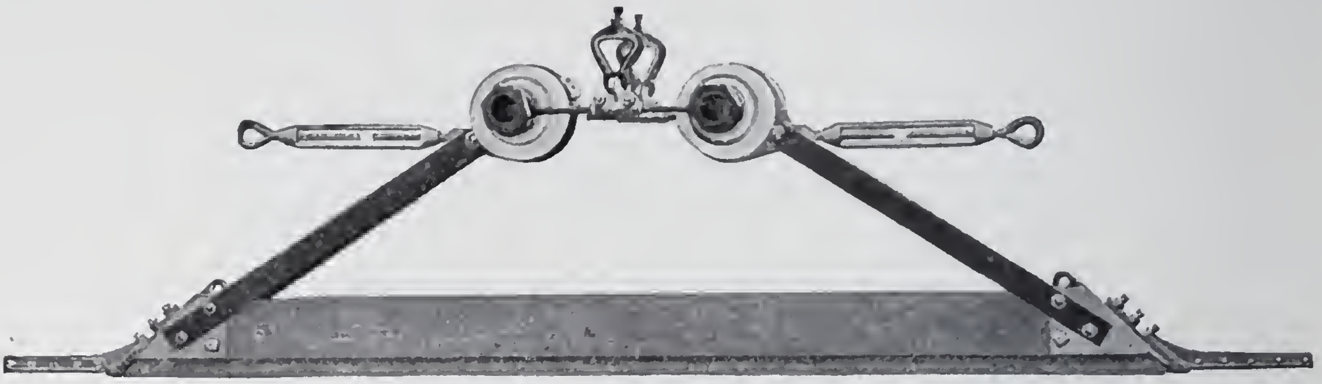


Fig. 10.—Section Break.

seriously affect the speed. With alternating current, compensation for this drop may be obtained by means of a high voltage tap on the car transformer. The permissible percentage drop in the low tension distribution system largely determines the number of points at which power must be supplied to the trolley. The relatively small current resulting from the use of high voltage tends to reduce the drop per mile. Again, the allowable percentage drop means that there may

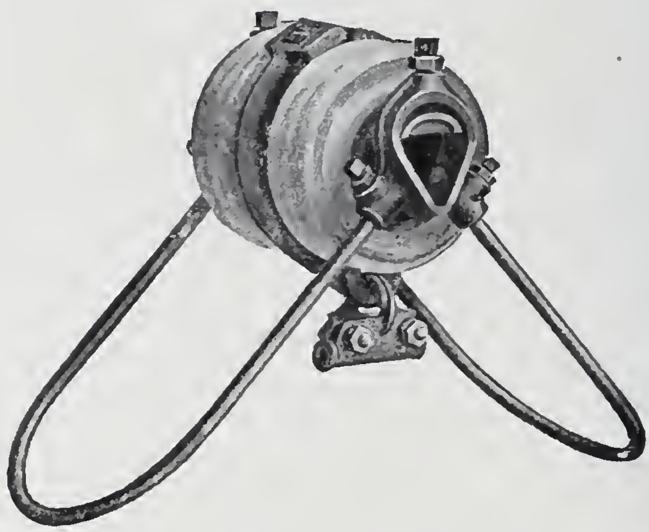


Fig. 11.—Main Line Insulator.

be a greater actual volts drop at high voltage. The resultant tendency of these two relations is to reduce the amount of material in the supply circuit and to decrease the number of feeding points on a system where high voltage is used. In single phase systems this tendency is par-

tially counteracted by the fact that an electric circuit offers a greater impedance to alternating current than the amount of its ohmic resistance to direct current, and the drop with alternating current is dependent upon the impedance of the circuit, just as the drop with direct current is dependent on the circuit's ohmic resistance. The practical result of this feature of the single phase system is to first cut down the amount of overhead material to a definite quantity, and then space the feeding points to suit the drop permissible with this standard overhead construction at the voltage which seems best

FIG. 12.—DOUBLE CATENARY.

adapted to the problem in hand. The desirability of having a standard type of overhead construction is due to the fact that this reduces the cost of production, and consequently the cost to the customer, and also facilitates delivery from the factory.

Where transformer stations are used, the drop in the low tension distribution system should be limited to 10 percent maximum, because of the cumulative effect of the drops in transformers and high tension line. Where a line is fed entirely from the generators direct, the maximum trolley and track drop may be so high as 20 percent. By observing these limits of maximum drop the loss in the trolley and track system may be kept as low as 5 percent in the first case, and 10

percent in the second case, which is a decided improvement in efficiency over the 15 or 20 percent line loss often found in direct current practice.

Generally speaking, for short roads and light service, nothing would be gained by going beyond 3300 volts on the trolley. For high class interurban service on roads of moderate length and some cases of steam road electrification, 6600 volts is altogether satisfactory. For very long interurban roads operating trains, and for the electrification of steam roads, with frequent service, 11,000 volts trolley pressure will ordinarily work out to the best advantage. Up to the present time, this is the highest voltage to which it has been necessary to go in this country, but heavier traffic and longer lines may in the near future make advisable the consideration of even higher voltage, and it is altogether probable that within a few years we shall see lines in

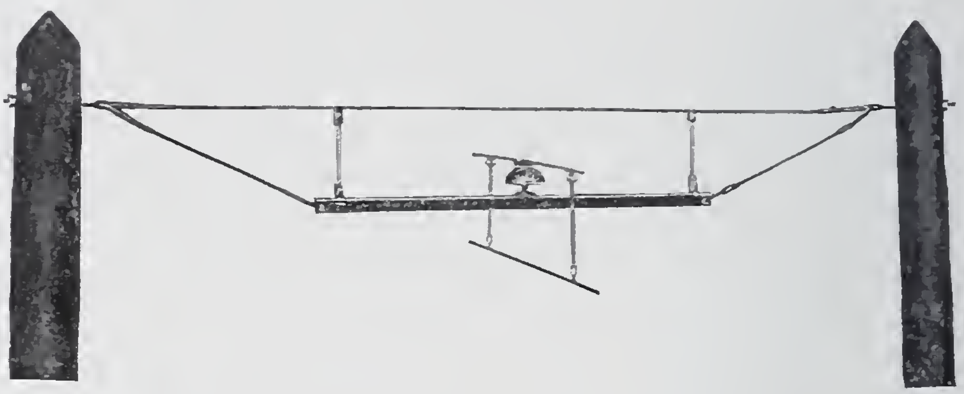


Fig. 13.—Single Catenary Cross-span Construction.

every-day operation under a trolley pressure of from 15,000 to 22,000 volts. In many cases it is feasible to use sufficiently high voltage on short roads, so that only one feeding point is required, and to locate the power plant at that point. Otherwise additional feeding points must be provided in the form of transformer stations.

Transformer Stations.

The transformer station contains one or more transformers with switching apparatus and lightning protection on both the high and low tension sides. The absence of rotating machinery, polyphase switching apparatus, and direct current switchboard leaves a station of unusual simplicity and one not requiring constant attendance. The transformer itself is simple and one of the most efficient pieces of electrical apparatus. It also has an exceedingly large momentary overload capacity. Since the station contains no rotaries and the transformer takes power direct from the high tension line and delivers it direct to the trolley, sufficient station capacity may be obtained

in one or at most only a few large units instead of the numerous units required by having a bank of small transformers for each rotary.

In comparison with the A. C.-D. C. substation, with its rotary converters or motor-generator sets, the transformer station is much simpler and more reliable. The transformers are not affected by short circuits as are rotary converters. There is no flashing, dropping out of step, or synchronizing. Throughout the system accidents are less apt to be destructive with high voltage alternating current than with direct current, because of the smaller currents and conductors used and the self-induction of the circuits and apparatus employed. This difference is probably nowhere more noticeable than in the sub-

Fig. 14.—Transformer Station.

station operation of the two systems. Since the transformer station contains no moving machinery and only such apparatus as is highly reliable, it is not necessary to provide constant attendance for these stations. All that is required is an occasional inspection by the men who patrol the transmission and distributing lines.

In addition to the small gain in efficiency resulting from the use of larger transformer units, there is a large gain in this item through the absence of rotary converters. The average efficiency of the rotaries on a system would probably not exceed 92 percent, because of the periodic heavy overloads and low average load factor, which is even less than that of the power-house.

The reduced number, greater simplicity, and better efficiency of the substations, together with the absence of constant attendance

in the same, constitutes the second large item of saving in first cost and operation by the single phase system in comparison with the direct current system.

Transmission Line.

It is possible to use either three phase or single phase transmission. Three phase transmission to transformer stations is ordinarily equivalent to that for rotary substations. When transformer stations are fed from a single phase circuit at a given voltage, more copper will be required than for three phase transmission at the same voltage, but at the same time the number of insulators is reduced with single phase. The amount of copper required for single phase operation may be reduced by going to a higher transmission voltage. On many interurban roads increase of voltage for this service is not necessary because the 22,000 or 33,000 volts which would be ordinarily used for three phase transmission would still be sufficient for single phase transmission when making use of No. 6 B. & S. copper wires, and it is not desirable to go below this size on account of mechanical strength. In fact, many engineers prefer taking No. 4 B. &. S. copper wire as the minimum size for transmission circuits.

With three phase transmission and the transformer stations distributed among the phases, a sectional trolley is necessary, each station supplying its own section. With single phase transmission there is a continuous trolley between feeding points with the attendant reduction in the number of feeding points. Where three phase transmission is employed the number of transformer stations may be made the same as with single phase transmission by making use of three to two phase transformation, the trolley being sectionalized in front of the station and the two secondary phases feeding alternate sections of the trolley. In this case, however, there is a multiplication of apparatus in individual stations.

Consequently, the question of transmission reduces, in general, to either a single phase line with a certain amount of copper and a certain number of insulators, or a three phase line with one-third less copper and fifty percent more insulators, together with either more feeding points or more apparatus per station. If the total cost for transmission and transformer stations is found to be greater with single phase than with three phase transmission, it is still a question whether it is not better to put the additional money into copper, which has a small rate of depreciation, and may even appreciate,

rather than to have the additional units of transforming and switching apparatus and the increased number of weak points on the line which accompany three phase transmission.

The maximum drop in the high tension line should be not more than 10 percent. With this maximum drop in the line the average loss will be 5 percent or less usually.

Power Station.

The power-house for a single phase road will contain alternating current generators, D. C. exciters, switchboard, raising transformers, lightning protection, and high tension switching apparatus. Aside from the generators, the power-house apparatus does not concern the system particularly.

The generators may be either single phase or polyphase. Polyphase generators have the advantage in first cost, but labor under the disadvantage of having the load unbalanced between the phases, with the attendant bad effect on voltage regulation, and of inability to concentrate all power along one section of the line if necessary. Single phase generation requires larger and more expensive machines than three phase, but the total power of the generating station is available on any section of the line, and the power-house voltage may be maintained constant by the use of the Tirrill regulator, irrespective of the load conditions.

In this country the manufacturers of single phase railway apparatus have up to the present time held to the frequency of 25 cycles. If power is available at a different frequency and can be purchased to better advantage than it can be independently generated, the power-house will be replaced by a frequency-changing station containing motor-generator sets. The motor-generator sets may be driven by either induction motors or synchronous motors. In connection with them storage batteries may be used for reducing the peak load by the addition of a direct current machine which will act alternately as motor and generator.

As to prime movers, steam turbines operate particularly well under conditions of varying load, such as railway service, and in addition have a high economy. Gas engines also have been found to give excellent service in this class of work even when operating alternators in parallel. In selecting the capacity of gas engines, however, it is necessary to determine fairly accurately the maximum load to which they will

be subjected, because of the small and definite overload capacity of this type of prime mover with the present method of rating.

The generators may be wound for the trolley voltage and power may be supplied to the trolley direct without any intervening transformers. Protection from lightning is furnished by choke coils in the trolley circuit before it leaves the power-house and by having the trolley line itself well protected.

With single phase generators, shop power may be obtained by using single phase induction motors or single phase series motors, or direct current from the spare exciter may be utilized for this purpose.

System.

As to the efficiency of A. C. systems which seem advantageous from the standpoint of first cost, it is seen that about the same amount of power is required from the low tension distribution system for operation on either single phase or direct current. But there is a large gain in efficiency for the single phase system in the trolley and track system and substations. Some of this advantage may be lost in the transmission line, yet with a proper layout the resultant efficiency for the whole system should be in favor of alternating current.

The principal advantages and faults of the single phase system in comparison with the ordinary direct current system are as follows:

Advantages.	Disadvantages.
Low voltage motor.	Motor has 3 percent to 5 percent lower efficiency.
No flashing or bucking.	
Balanced magnetic pull on armature.	More brushes.
Motors will operate on direct current.	
Voltage control avoiding rheostatic losses.	
Fewer notches on controller.	
Greater number of efficient running speeds.	
Multiple unit control is simpler.	
Greater ability to make up lost time.	Heavier and more expensive car equipments.
Overhead contact line.	More expensive contact line (neglecting third rail).
More reliable contact line.	
Sliding contact collector.	
No feeders.	
Substations are fewer, simpler, more reliable, more efficient, cheaper, and require no attendance.	
Fewer insulators on transmission line.	Transmission line may take more copper or higher voltage.
Entire system is simpler and more flexible and may have decreased first cost and operating expenses.	Larger and more expensive generators.

In comparison with the three phase railway system using induction motors on the cars, the single phase system shows the following:

Advantages.	Disadvantages.
Correct motor characteristic.	Less efficient motor.
All motors working at all speeds.	Equipments may be heavier.
Greater number of efficient running speeds.	
Voltage control.	
Single contact line and collector.	
Higher voltage on contact line.	Transmission line may be more expensive.
Fewer and simpler transformer stations.	Larger and more expensive generators.

Of course, in the practical operation of the pioneer single phase systems installed, some troubles have been experienced. However, these troubles have not been inherent in the system or apparatus, but have been due chiefly to defective material and improper design. They have not been more numerous than might reasonably be expected in the developmnt of any new system using new apparatus, and have been easily remedied.

Application.

The single phase system is not adapted to all branches of traction work. For instance, in cities the trolley voltage would probably be limited to a value that would preclude the use of single phase apparatus. Again, it is evidently not suited to mine haulage in general, where space is limited and the necessary high voltage trolley would be within easy reach of the workman. Also, certain short interurban roads may show an advantage in favor of the 550 to 650 volts direct current system.

However, the single phase system is especially suited to general interurban work for moderate and long distances, chiefly because of the reduction in the number and cost of substations and low-tension distribution system, and because of the absence of constant substation attendance. It is also well adapted to heavy service, frequent or infrequent, such as the electrification of an existing suburban steam service, branch lines of steam roads, through steam lines, and mountain grades. Any particular service may be operated on the locomotive or multiple unit plan, the choice of locomotives or multiple unit trains for the electrification of steam lines being largely a matter of the local conditions of the particular project.

On lines with numerous or long heavy grades recuperation of power

when running down grade is practicable with single phase equipments, as well as with three phase equipments. The polyphase induction motors will return power to the line at only two speeds without resistance in the circuit, whereas single phase equipments will do so at practically all speeds. In the act of recuperation of power the train is braked and a large amount of the wear and tear on the wheels, brake shoes, and track is avoided. To accomplish this result with single

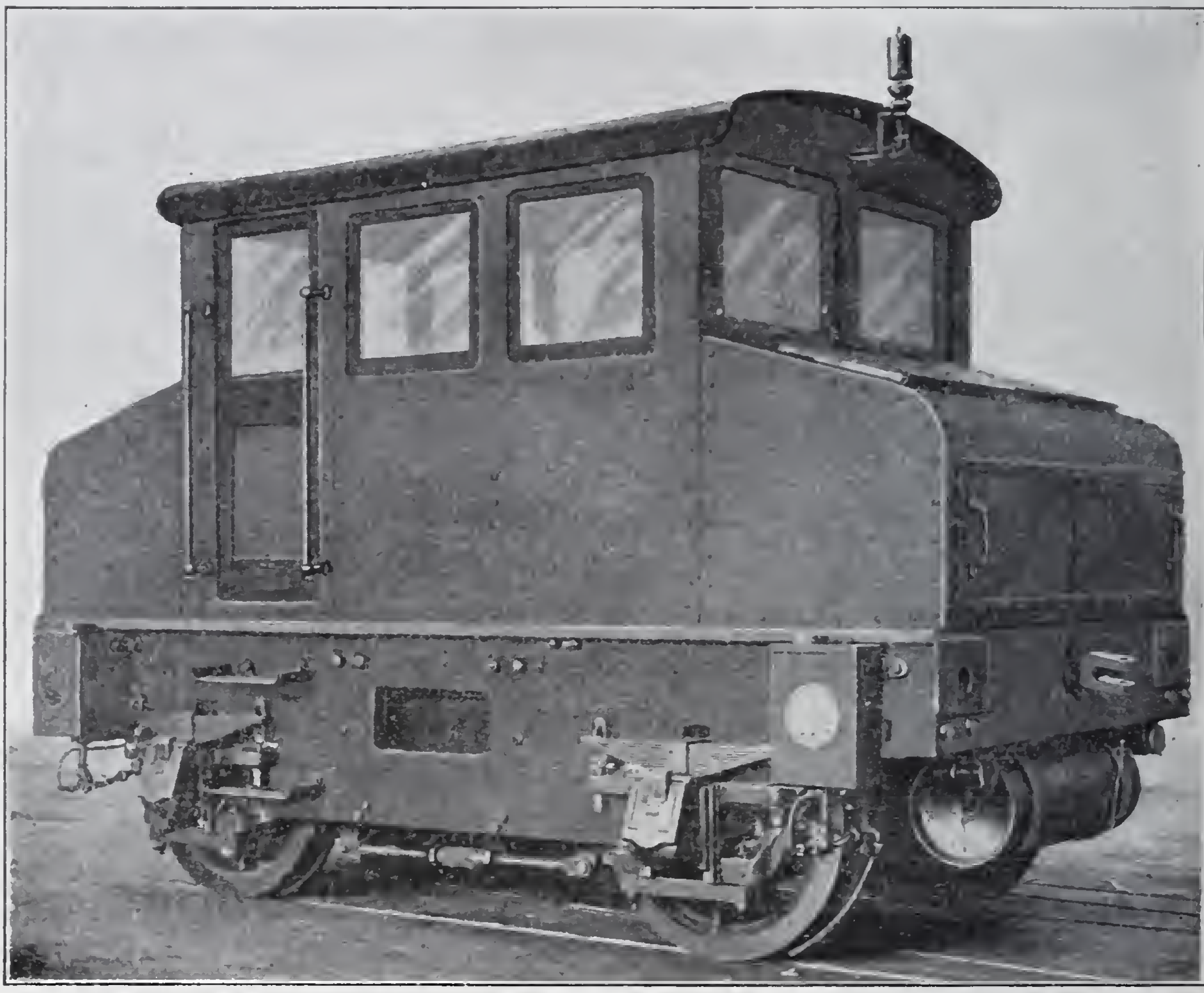


Fig. 15.—Swedish Locomotive.

phase equipments it is, of course, necessary to provide a certain amount of special control apparatus in addition to that ordinarily required.

Locomotives.

Until recently the field of electric locomotives has been largely confined to industrial, mine, and light freight haulage. The introduction of electric locomotives on various steam roads entering New York city, namely, the Pennsylvania, New York Central, and New York, New Haven and Hartford Railways, and their adoption for

the St. Clair and Simplon tunnels, and for general freight haulage on the Spokane and Inland Railway, indicate that another and heavier field for electric traction is open. Some of the general points in favor of electric locomotives for heavy traction work as against steam locomotives may be of interest.

The steam locomotive develops its maximum horsepower at high speeds, consequently in starting large loads and in ascending heavy grades the locomotive is working at reduced output and reduced efficiency. The electric locomotive will, with few exceptions, give

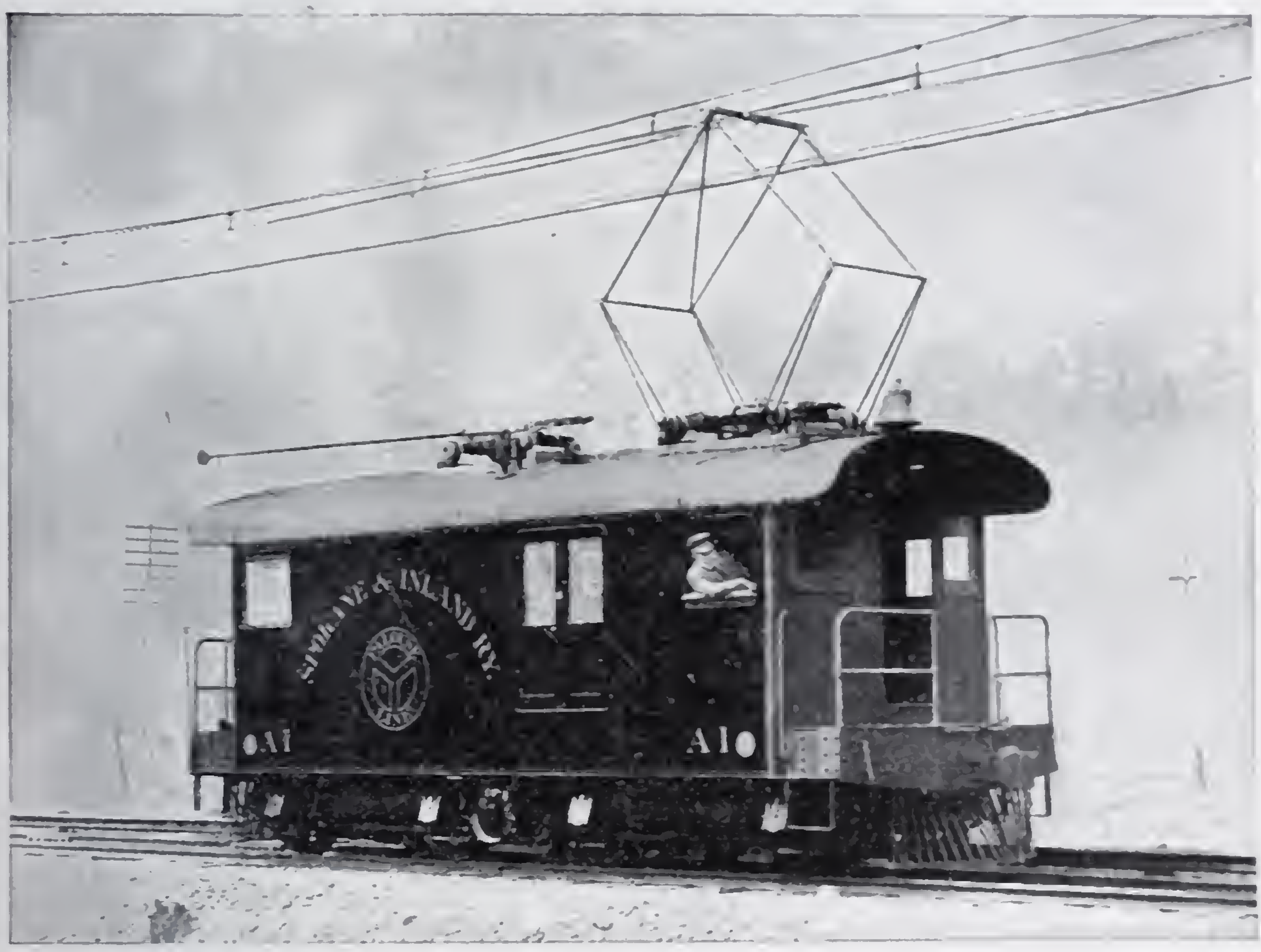


FIG. 16.—SPOKANE & INLAND RY. SINGLE-PHASE LOCOMOTIVE.

increased horsepower with increased load up to the point of slipping the wheels. The electric locomotive may be designed with the entire locomotive weight on the drivers, and thus the percentage of dead weight in a train be reduced to a minimum. Two or more locomotives may be operated as a single unit without increase in train crew over the number necessary for one unit, the limit in the number of units so operated being determined by the maximum draw-bar strains which the draft gear of the train is capable of withstanding. This multiple operation without increase of train crew becomes an impor-

tant factor in the electrification of mountain grades, where there are heavy trains operated at frequent intervals. A system using electric

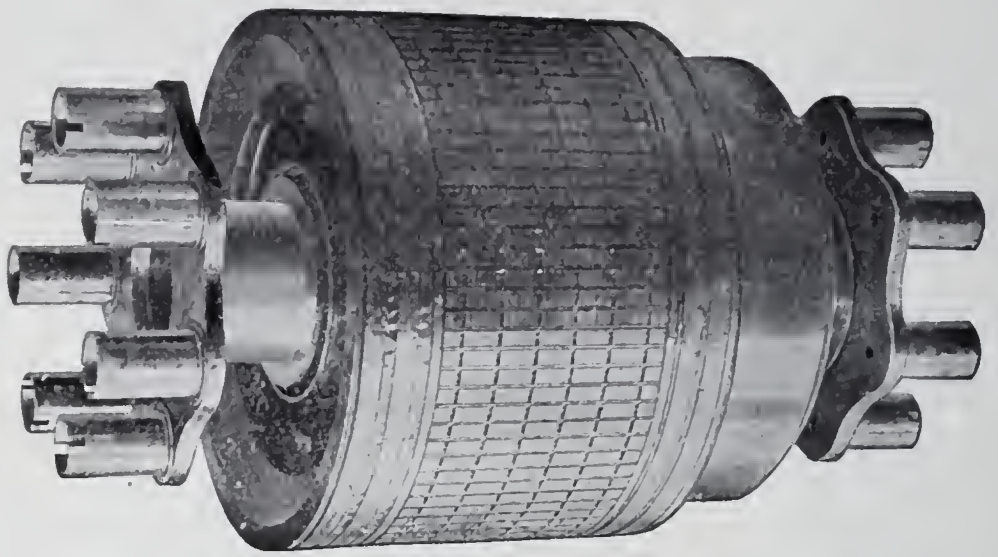


Fig. 17.—N. Y. N. H. & H. R. R. Motor Armature.

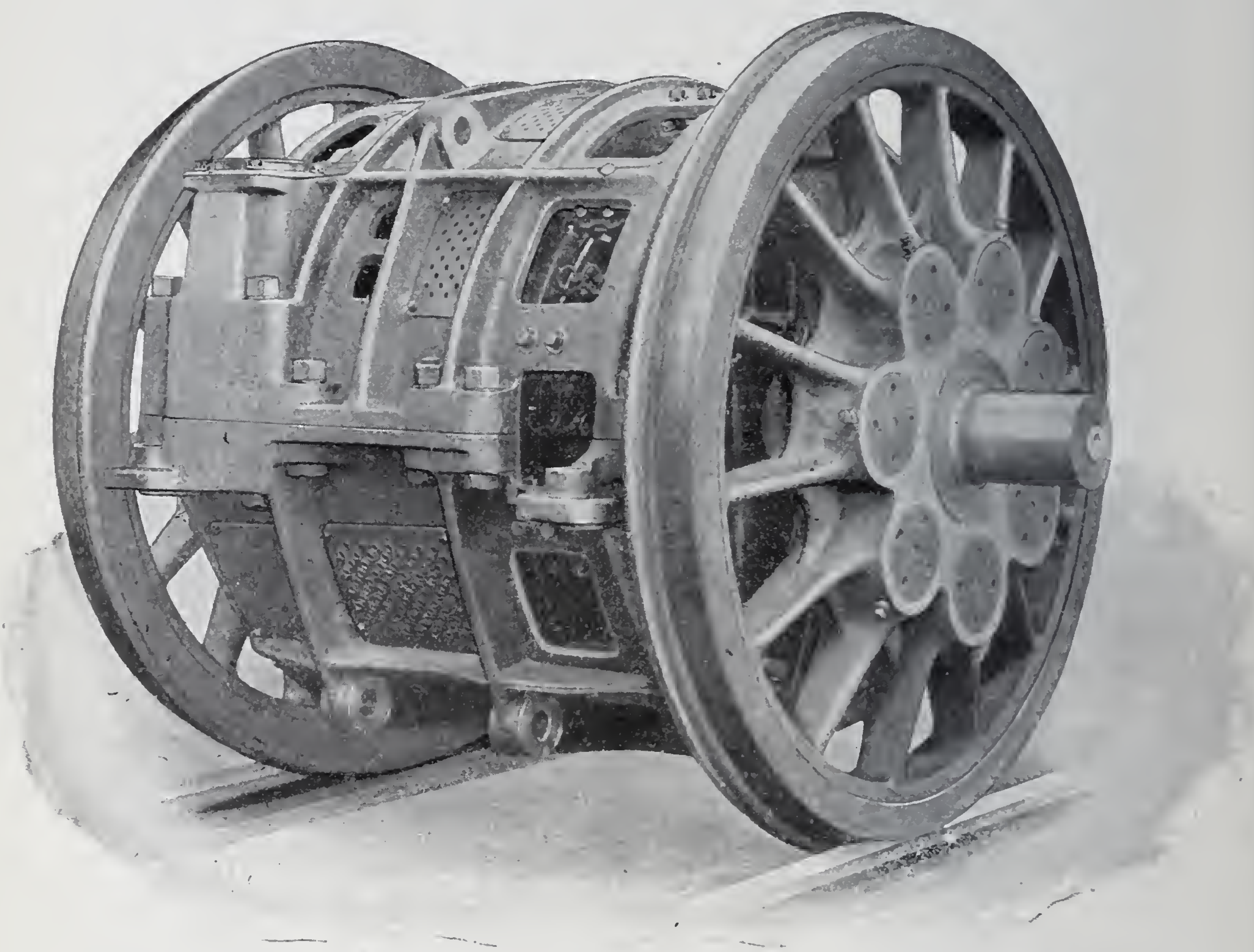


Fig. 18.—N. Y. N. H. & H. R. R. Motor and Driving Wheels.

locomotives obtains the benefit of a centralized power-house and its consequent economy. The great flexibility of electric systems is

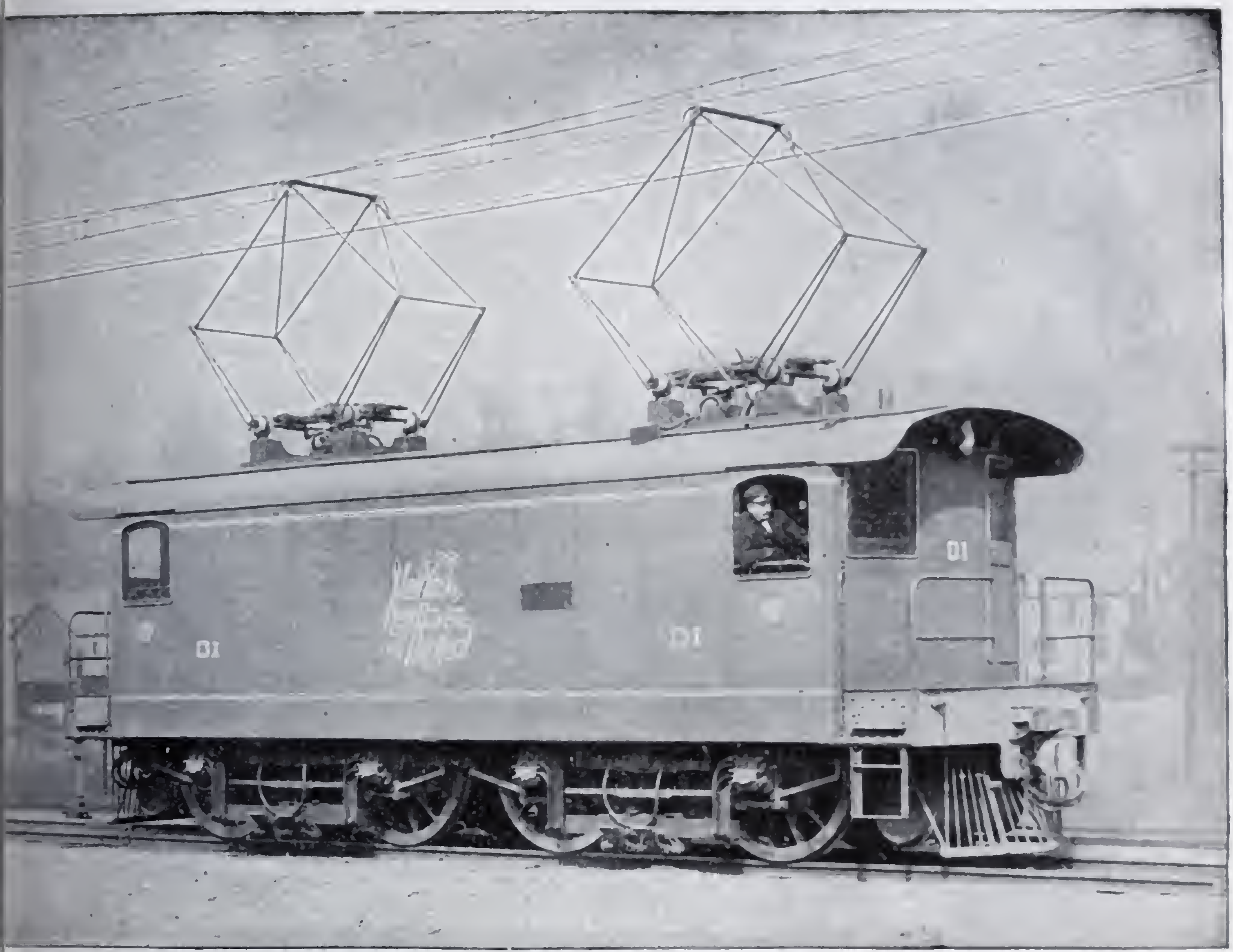


FIG. 19.—N. Y. N. H. & H. R. R. SINGLE-PHASE LOCOMOTIVE.

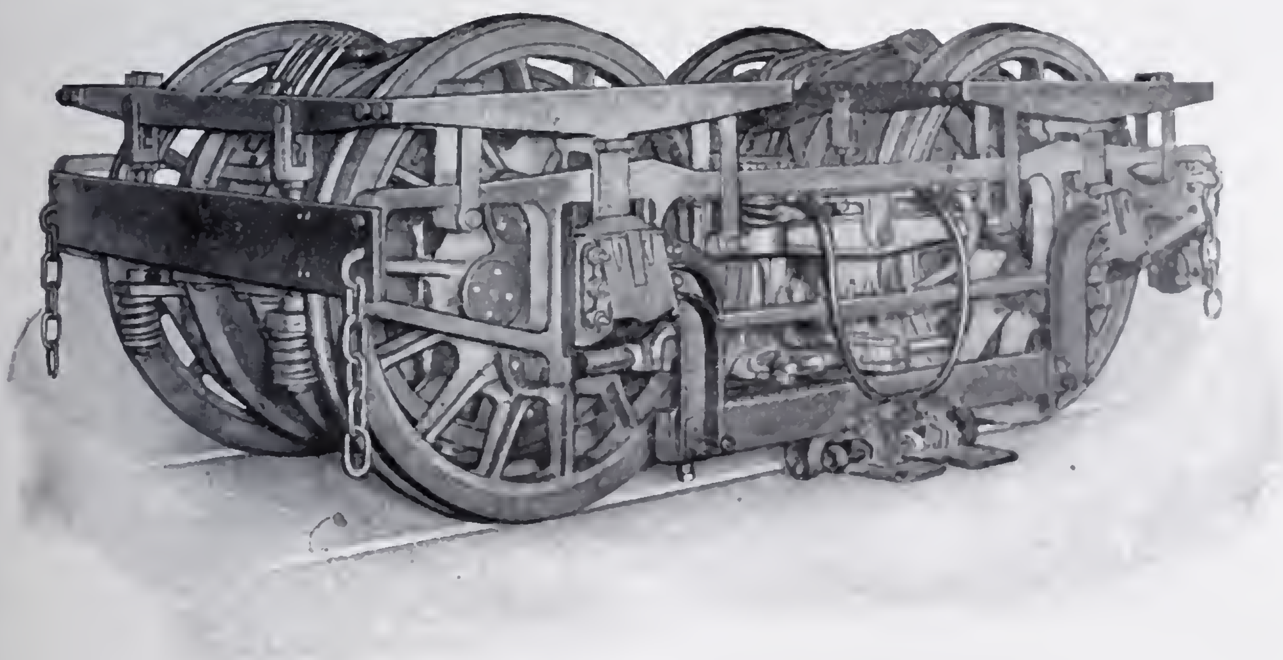


FIG. 20.—N. Y. N. H. & H. R. R. MOTORS ON TRUCK.

also an important item. Practically all of the power of the generating station may be concentrated on a particular section, if necessary. With electric locomotives, stops for taking on water and coal are abolished. Increased speed on grades is possible. This is an important item where a section of road has reached the limit of its capacity with steam operation, both as to the number and size of trains. With three phase or single phase locomotives there is the additional advantage of recuperation of power from trains on descending grades.

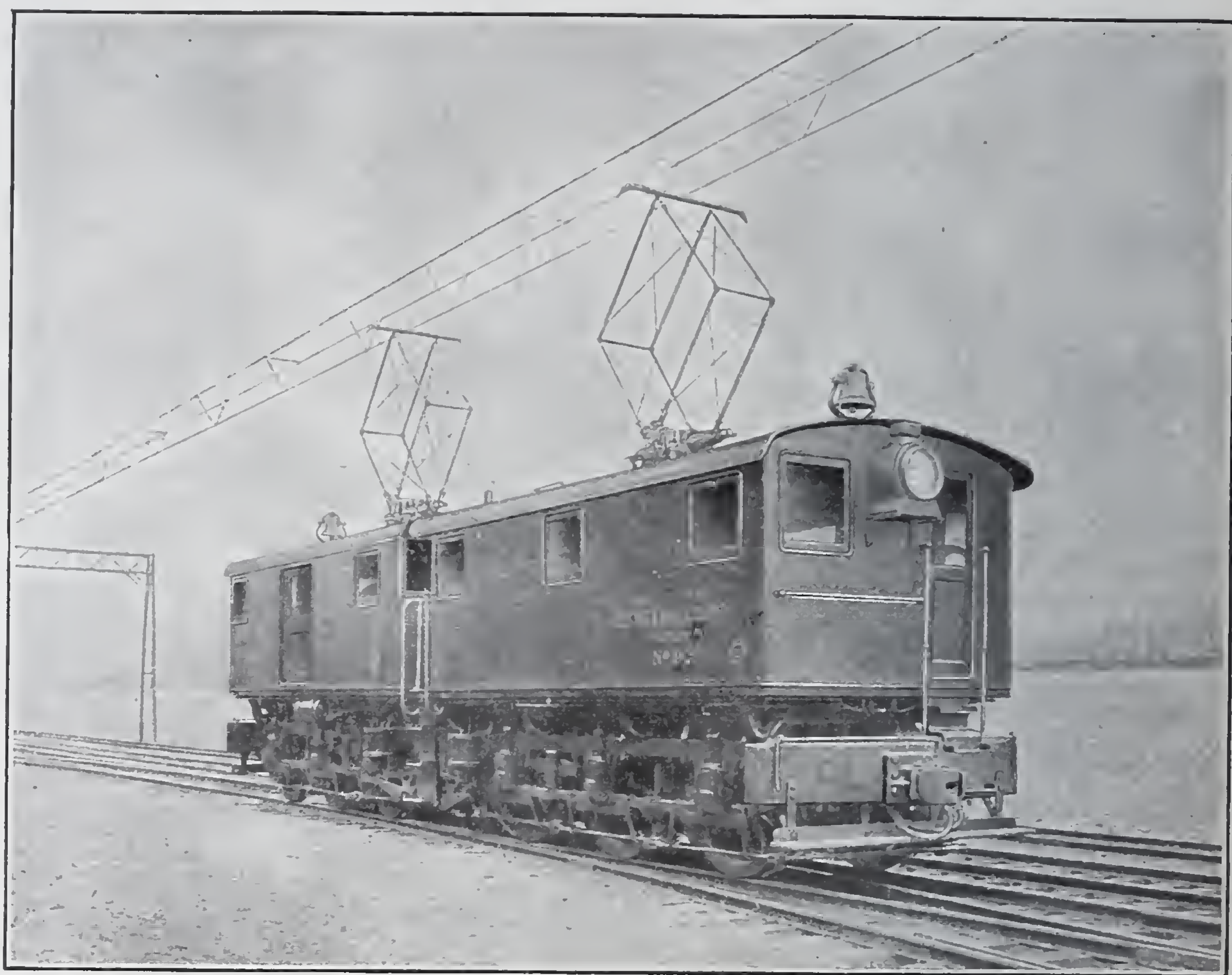


FIG. 21.—125-TON FREIGHT LOCOMOTIVE.

The building of electric locomotives in capacities comparable with existing steam locomotives is no longer a mere possibility. It has been accomplished in recent years with direct current equipments, and within the past two years two distinct types of single phase locomotives have been developed and built whose operation may be compared to that of steam locomotives. The locomotives for the St. Clair tunnel are comparable to steam freight locomotives, and the locomotives of the New York, New Haven and Hartford Railroad are for a distinctly high speed passenger service.

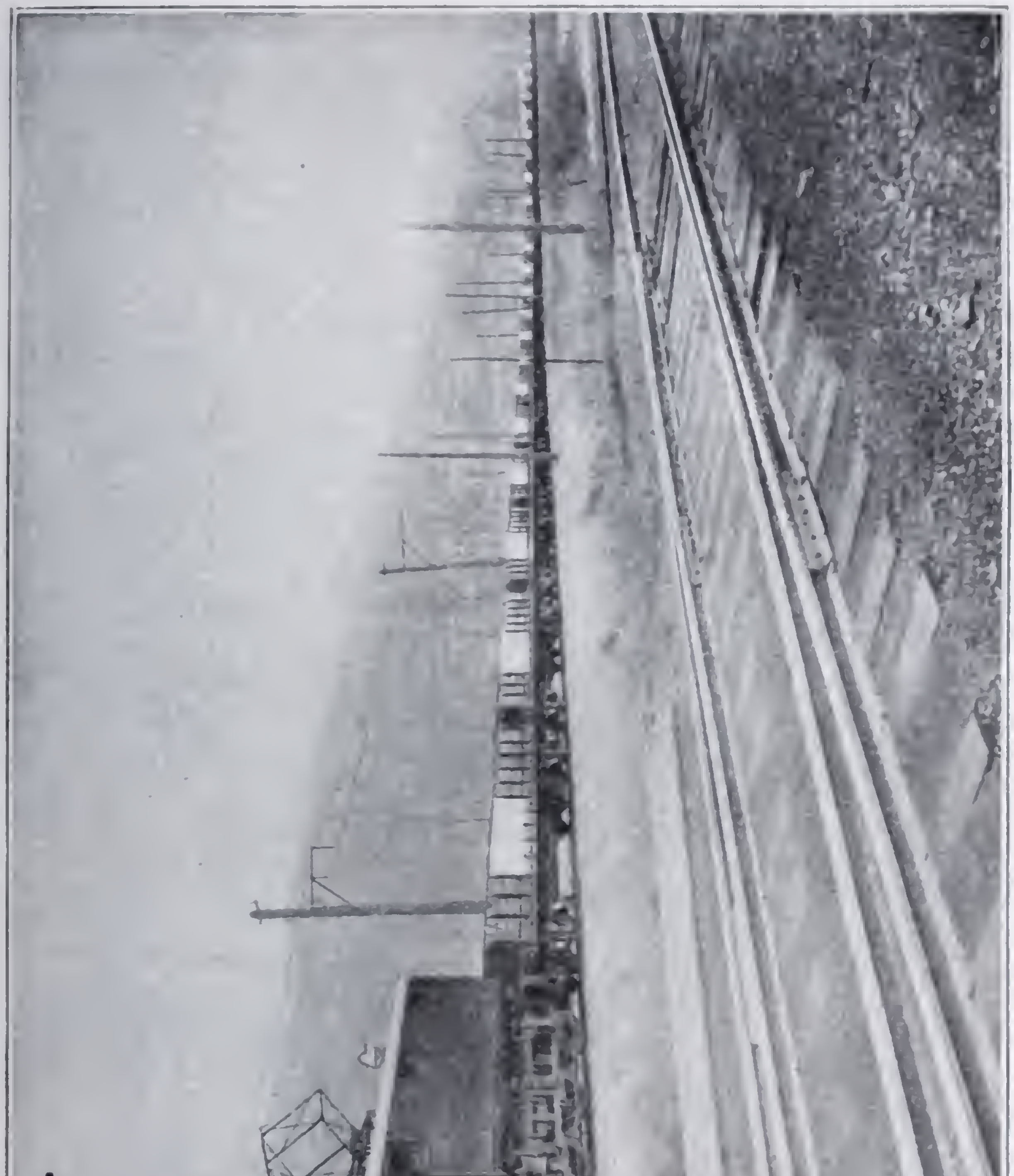


FIG. 22.—125-TON LOCOMOTIVE, HAULING 50-CAR TRAIN.

ELECTRIC RAILWAY SYSTEMS.

(1) Simple D. C.	(2) A. C.-D. C.	(3) Simple Single Phase.	(4) One Φ with Transformer Station.	(5) (2) and (4) Combined.
D. C. generators.	A. C. generators.	A. C. generators.	A. C. generators.	A. C. generators.
Switchboard.	Switchboard.	Switchboard.	Switchboard.	Switchboard.
....	Raising transformer.	....	Raising transformer.	Raising transformer.
....	High tension line.	....	High tension line.	High tension line.
....	Lowering transformers.	....	Lowering transformers.	Lowering transformers.
....	Switchboard.	....	....	Switchboard.
....	Rotaries or motor-generators.	....	....	Rotaries or motor-generators.
....	Switchboard.	....	....	Switchboard.
Feeders.	Feeders.	....	....	Feeders.
Trolley and track.	Trolley and track.	Trolley and track.	Trolley and track.	Trolley and track.
Control resistance.	Control resistance.	....	....	Control resistance.
		Auto-transformer.	Auto-transformer.	Auto-transformer.
D. C. motors.	D. C. motors.	One Φ motors.	One Φ motors.	One Φ motors.

LOCOMOTIVE DATA—APPROXIMATE.

	N. Y. N. H. & H. Locomotive.	Spokane & Inland Locomotive.	No. 9 Locomotive.
Type	A. C.-D. C.	A. C.-D. C.	A. C.
Gear ratio	Gearless.	17 : 72	18 : 95
Performance spec.	To haul 200-ton train on 2.22 mile run—45 sec. stop—26.2 m. p. h.	To haul six 50-ton cars up 8 mi. of 2% grade.	To haul 1000-ton train up 2% grade at 10 m. p. h.
Tons weight	85	49	125
Length	36′ 0″	29′ $\frac{3}{4}$″	46′ 2″
Width	10′ 0″	9′ 6″	9′ 6″
Height over trolley	14′ 7″	13′ 5″	14′ 0″
Rigid wheel base	8′ 0″	7′ 4″	12′ 8″
Total wheel base	22′ 6″	21′ 1″	37′ 8″
Wheel diameter	62″	38″	62″
No. of motors	4	4	6
H. P. of locomotive	1,000	600	1,440
Full load D. B. P.-A.C.	7,150	15,200	48,000
Full load speed-A. C.	44	14	10
Cont. D. B. P.-A. C.	4,400	4,800	13,000
Continuous speed-A. C.	51	25	22.5
Max. D. B. P.-A. C.	15,000	23,700	90,000

Of course, steam locomotive engineers have little to fear at present from the possible introduction of electricity for through service on long trunk lines. However, there is a large field for electric traction in terminal work and heavy haulage on steep grades. Wherever the electrification of a portion of a steam railroad is contemplated, the matter should be taken up carefully and a complete study made of the conditions and possibilities of the system when operated by steam and by electricity as well. In considering electrification the com-

parison should not be confined to a single system, but a thorough investigation of the various electric systems should be made so as to obtain a correct understanding of the operating possibilities and costs for each system. When such a study is made, the several systems may be compared and a satisfactory conclusion reached which will leave small opportunity for any guessing or speculating afterward on what might have been had another system been adopted.

DISCUSSION.

Wm. C. L. Eglin.—I have been very much interested in the exceedingly able presentation of this subject this evening, and I am sorry that we did not get a little further into large trunk line systems that enter into the question when it is considered from the point of view of the trunk line system, which is different from the interurban system, particularly the question of frequency, and I would like very much if Mr. Wynne could give us some information along that line. As I understand the question of freight handling on a trunk line system, the low speeds necessitate a very much lower frequency than is at present in use, and which complicates not only the generating station, but also the use of the single motor.

Carl Hering.—How does the cost of the locomotives themselves compare? Mr. Wynne proposes to use as high as 20,000 volts on the trolley wire. I would like to ask whether that is not dangerously high, and what precautions are taken to minimize the danger of such wires breaking and coming in contact with persons either in the cars or on the tracks.

I would also like to ask what progress has been made in single-phase traction abroad. Polyphase A. C. traction was used abroad before it was used here. But I believe that in America we are operating more single-phase lines than abroad. Seven years ago I rode in a number of lines in Europe operated by the three-phase system, and while they seemed to be satisfactory in many respects, they did not seem to be altogether so. Three-phase traction has not, I believe, made any progress at all in this country.

John J. Gibson.—It will be of interest to the members to learn of some work which has been done by the Engineering Department of the N. Y., N. H., and Hartford Railroad in order to determine the conditions of their traffic on the division which they are electrifying. That road during the past year has taken ten freight locomotives and ten passenger locomotives and has kept a careful record of the exact cost of maintaining them. This record has been kept with particular care in order to ascertain the exact facts so that data might be obtained which would be of more value than the usual data kept on such subjects by steam railroads. It was found that it cost 8.1 cents per locomotive mile to maintain the freight locomotives, and 5.6 cents per locomotive mile to maintain the passenger locomotives. The most reliable figures obtainable at present on the cost of maintaining electric locomotives come from abroad, where they have had electric locomotives in operation for a sufficient length of time to make such data of value. On the Valtellina Line in Italy it has been found that the cost of maintaining electric locomotives is 1.8 cent per locomotive mile. The General Electric Com-

pany states that the cost of maintaining an electric locomotive built by them for the New York Central Railroad and run 50,000 miles on test track is less than 1.25 cent per locomotive mile.

The New Haven people also made measurements of the power required to draw an express train from New Haven to New York, and they put men on the cylinders of a locomotive behind wind shields, who took indicator cards, two every twenty seconds, alternating for each end of the cylinder, without stopping, on the hour and a half run from New Haven to New York, and they did not miss a single card. From these figures they were able to determine the power consumption of this run, and also what they were primarily after, they were able to determine the train resistance of this run at all points on the division. This work had to be done very carefully, and even after the infinite pains which were taken, they have what is, at the very best, only an approximation.

Consider the ease with which this same data could be obtained with an electric locomotive. All that would be necessary to be done would be to read a few meters. This is an advantage in electric operation, which perhaps those of us who are in the electrical business do not so fully appreciate. In the operation of railroads, as in any other business, it is necessary to charge expenses to the proper accounts, and the bookkeeping feature is more or less important. Electric operation makes possible an exact determination of power consumption, so that it may be charged to the proper account, and it makes such determination an easy matter, instead of a very difficult one, as in the case of steam.

It is generally conceded that the cost of power by electric operation is less than that required by steam operation. At the recent meeting of the American Institute of Electrical Engineers in New York City, at which Mr. L. B. Stillwell read his paper on "The Substitution of the Electric Motor for the Steam Locomotive," it was generally agreed upon that cost of power from electric operation effected a saving of from 15 to 18 per cent. over the cost of power by steam operation.

The greatly reduced cost of maintenance, the lower cost of power, and the ease with which measurements can be made, from a trio of advantages which are not to be denied.

JOHN C. TRAUTWINE, JR.—I am not surprised to learn that the operation of electric locomotives is less expensive than that of steam locomotives, but the figures given state only the cost per *train* mile, and, in order to judge properly between the two systems, we must know how the *loads* compared. Can the author give us the costs of operation per *ton* mile?

JOHN J. GIBSON.—I am not sure that I can answer that question accurately. That point was answered, or rather mentioned, in Mr. Stillwell's paper in New York, and is a matter of record, but my memory does not serve me sufficiently well. It is less, however, per ton mile.

HENRY H. QUIMBY.—There are other interests than the electrical concerned with these developments. I notice that the paper stated that the bulk of the weight of the electric locomotive was on the drivers. I notice in the tables of weights and wheel bases that the 85-ton locomotive was given a rigid wheel base of 8 feet, which would not sound as though it were a driver, and tax a total wheel base of 22 feet 6 inches; and on the 125-ton locomotive the rigid wheel base was 12 feet 8 inches with a total wheel base of 37 feet 8 inches, and the question that

occurs to me is, are there such loads on the axles that bridges have not been designed to carry them?

F. E. WYNNE.—In the matter of frequency, I may say that it is only recently that this matter has been brought up. The first 125-ton locomotive was operated on 25 cycles, showing that a very good locomotive can be built for that frequency. Fifteen cycles would seem better because the locomotive is somewhat lighter, has a better power factor and has as good efficiency, and being lighter it will be somewhat cheaper. The total weight of the equipment on the locomotive will be somewhat less, and although the transformer weight will be increased to a certain extent, it is not sufficient to overbalance the gain in weight of the motors. The lower frequency also gives a longer distance between transformer stations; that is, longer feeding distances in the trolley line, and high-tension line without increased voltage and with the same losses. Low frequency is handicapped to a certain extent at present by the fact that it is rather hard to design suitable steam turbines of small capacity for driving 15-cycle generators. In larger capacities it is easy to design steam turbines. The turbine seems to be the thing nowadays for railway power supply, and the difficulty of designing it in small sizes for slow speed may put some limitation on the application of 15 cycles, but, of course, in heavy traction work where large units are used, the turbine will be eminently satisfactory. I think, personally, that 15 cycles will eventually work out all right. A great many roads of the heavy class will adopt 15 cycles if they adopt A. C. at all.

In answer to Mr. Hering's question, as to danger to passengers and others from high trolley voltage, I might say that 22,000 volts is no more dangerous than 3300 or 6600 volts; the mechanical construction of the trolley line takes care of the high voltage. The messenger wire is strong and will support the trolley and its own weight, and is designed to support these weights under all and any conditions of wind pressure and snow and sleet that may occur. If a trolley wire breaks next to one of the hangers, the maximum distance it can come down is ten feet. The minimum height of the wire is eighteen feet, and supposing a wire were to break as a car was passing under it, the metal roof covering would protect it. In striking this grounded metal, the wire would do no harm, but would ground the trolley circuit, throwing the breakers in the station, and the power cannot be put on again until the ground is removed. Therefore the question of danger is not very great. If the wire falls and strikes a pole, or anything at all which will produce a ground the danger is promptly eliminated.

As to the relative cost of the two kinds of locomotives, the electric locomotive is a great deal more expensive, but the extra expense of first cost is more than made up in economy of operation and saving in operating expenses. The item of maintenance is not fully determined yet. The indications are that the electric locomotive will require slightly less for maintenance. Ordinarily the same service can be maintained by fewer electric locomotives because the stops for coal and water are cut out and there are no fire-boxes and boilers to clean.

As to the question of the relation between a locomotive mile and a train mile, the following will probably indicate the comparison. Some figures were made up not very long ago comparing the operation of steam and electricity for three roads, taking each road separately of a certain length with a fixed weight of train and fixed weight of locomotive, the electric being the lighter; both electric and steam

locomotives operated as nearly as possible under the same conditions, and the comparison was made for the average service during a year. In one case where there was a great deal of switching, the comparison ran something like $1.16 per 1000 ton-miles for the steam locomotive, and, I think, 71 cents per 1000 ton-miles for the electric, that being the most favorable case of comparison. In the case of through runs for the trains it varied from something like 23 cents per 1000 ton-miles for the steam and 15 cents per 1000 ton-miles for the electric. These figures are roughly approximate.

With reference to the strength of existing bridges to carry the electric locomotives, it will be noticed that with the 85-ton locomotive the load per axle is about 21 tons. In the 125-ton locomotive there are six axles, and the load is practically the same.

Of course these locomotives would be applicable generally to roads where the construction is up-to-date, and presumably the bridges are built according to up-to-date designs. So far as the weight on the drivers goes, you might take an American type of steam locomotive, and you would get 22 tons weight per axle. The wheels of the electric locomotive being 62 inches in diameter, the two drivers on the American type come almost as close together as a pair of drivers on the New Haven locomotive. The weights per axle are nearly the same.

PAPER NO. 1036.

METHODS AND ECONOMIC ASPECTS OF MODERN TIMBER PRESERVATION.

GELLERT ALLEMAN,

Read March 16, 1907.

STATISTICAL.

IN 1905 the various steam railways of the United States reported purchases of 77,981,227 cross-ties. Of this number 14,459,521, or 18.5 per cent., were used for new track and 63,521,706 for renewals. Making allowance for 2.9 per cent. of the trackage not reported, it is fair to assume that the consumption of cross-ties by steam railways in the United States was, in the year 1905, at least 81,562,150. It is fair to assume that at least 10,000,000 ties were used by electric lines in 1905, thus making the consumption about 91,500,000 ties. The cost of the 77,981,227 ties was $36,585,446.14—the average cost of the most expensive, or the oak tie, throughout the country being fifty-five cents, and the average cost of the cheapest tie, the redwood, of which less than half of one million (or .4 of 1 per cent.) were used, being twenty cents. Almost one-half of the ties used—44.5 per cent.—were some variety of the oak family. Assuming that the average tie contains thirty-six board feet, it follows that one and one-half billion board feet of oak were used for railroad-ties in 1905. This is just one-fourth of the total amount of oak lumber produced in that year. Pine ties of all varieties make up 23.5 per cent. of the total consumption, or 18,351,000.

There are no reliable figures showing the production of timbers intended for use in the construction of bridges and for use as piling. For this latter use alone I assume that at least two billion feet were used in 1905. When we recall that unmanufactured lumber to the value of $63,695,291 was sent out of this country in 1906, we get some vague idea of the enormous drain on our timber resources. The total amount of lumber cut in the United States during the last three years varies between 31 billion and 35 billion board feet per annum.

Of the railroad-ties used, 7,510,000,* or 10 per cent., received some treatment in order to lengthen their life. Practically all of the ties treated were of the cheaper soft woods, such as loblolly pine, long-leaf pine, short-leaf pine, hemlock, and tamarack; the hard pines, the oak ties, and the redwoods seldom being treated. Last year ten railway companies were operating their own plants, and there were many individual plants where preservative treatments were applied.

There are 800,000 miles of telephone poles in use in this country. This means that at least 72,000,000 poles are in service. The untreated poles have an average life of twelve years. For the maintenance of the present lines, 2,650,000 poles are required annually. There are no figures showing how many of these poles are treated. In south-eastern Texas, throughout Louisiana and Florida, most of the poles are creosoted. The poles in the long-distance lines from Washington to Columbus are creosoted—practically all cross-arms used by the Bell Telephone Co. receive a similar treatment, unless the arms are made of locust, which is now very scarce.

Methods.

The physical problems connected with the impregnation of timber are the same as those attendant upon the emptying and filling (or partial filling) of a series of semi-permeable capillary tubes closed at both ends. The wood cells of freshly felled timbers are filled with water, resins, starches, and air. These wood cells are lined with various materials, such as coniferin, vanillin, wood gum, tannin, etc., spoken of collectively as lignin or the lignone complex. In seasoned timber the water has evaporated, leaving the cell-walls filled with air and those organic compounds which are not volatile. By the seasoning process the cell-walls have stiffened up considerably, and are hard to penetrate. For this reason it is customary to place the timbers in air-tight cylinders, apply a vacuum, and then steam for several hours in order to soften up the cells. By this process the timber is saturated with water, which, together with the air and water-soluble compounds, is removed later by the application of a vacuum.

If this preliminary treatment with steam is properly carried out, the timber can be made to take up more readily the impregnating solution. We now have a series of wood cells or semi-permeable membranes, all of which, after the application of a vacuum, are supposedly empty or

* Compiled from Government reports. The Wood Preservers' Association reports that 16,418,326 ties were treated in 1905.

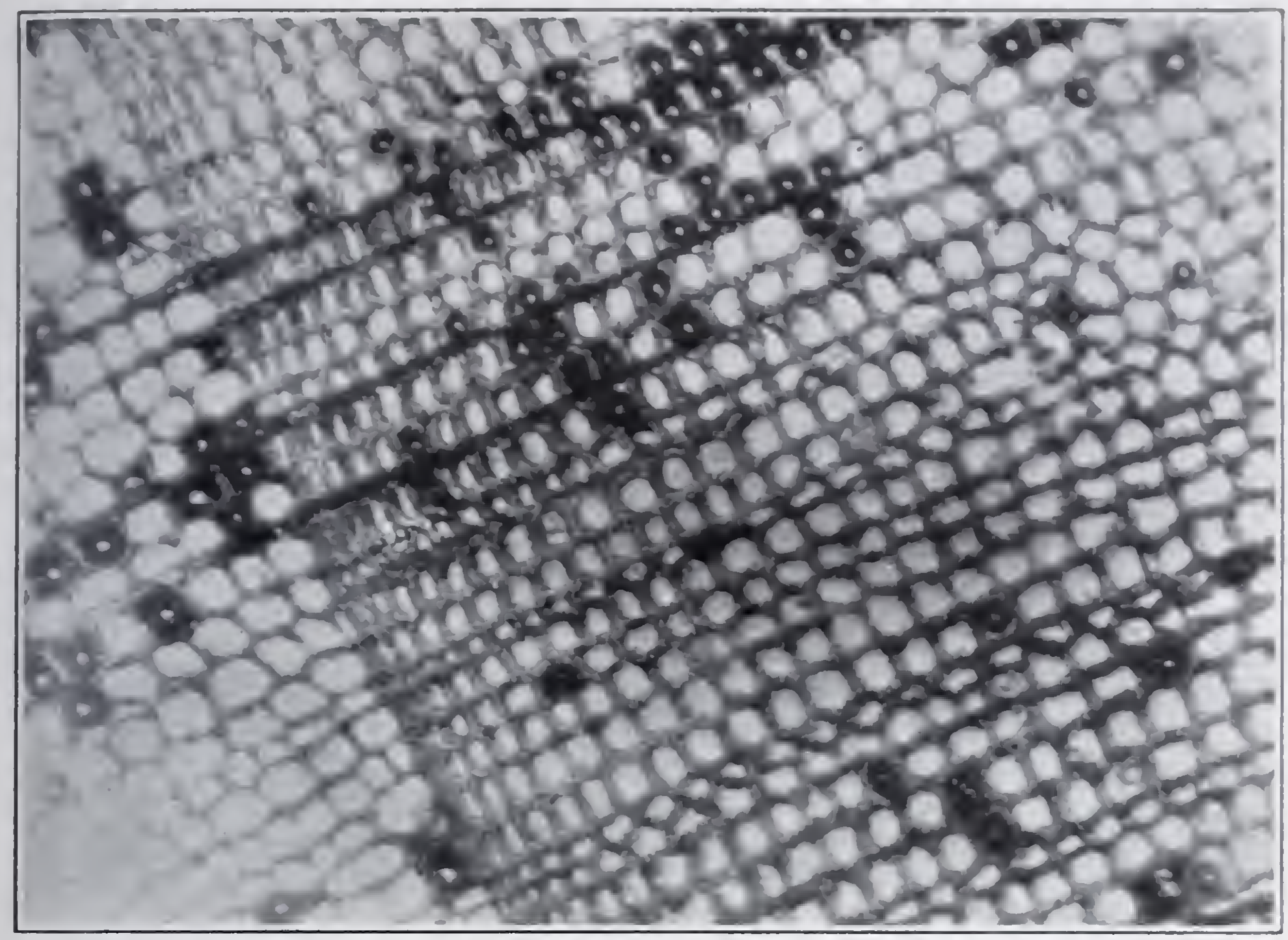


Plate 1.—Microphotograph of Loblolly Pine (Cross-section). Photographed by Gellert Alleman.

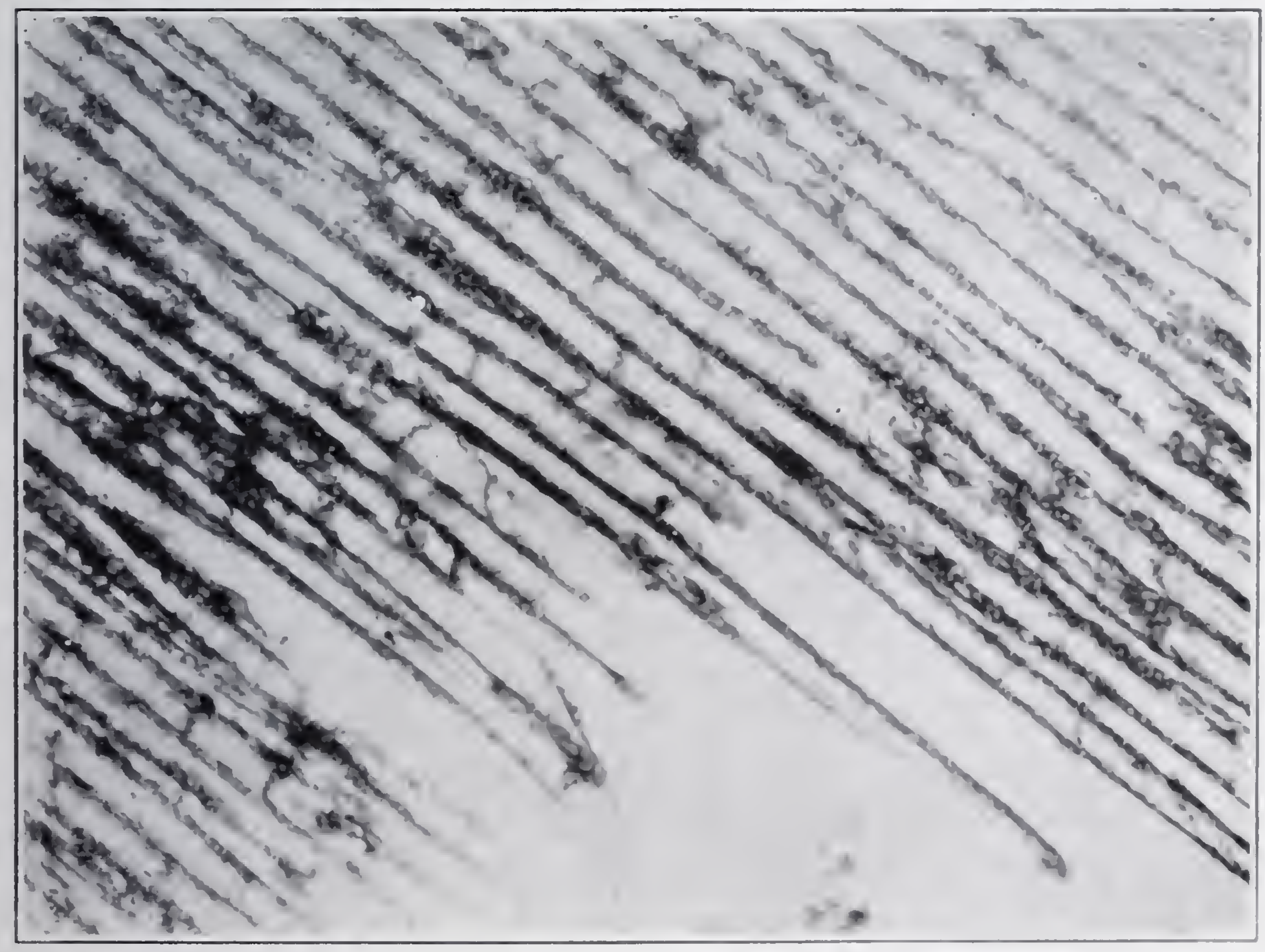


Plate 2.—Microphotograph of Longitudinal Section of Loblolly Pine. Photographed by Gellert Alleman.

partially so. While the vacuum is being held the impregnating solution is introduced, and when the cylinders are full pressure is applied until the desired quantity of material has been taken up by the timber. When this has been accomplished, the solution is pumped out of the cylinder, the doors opened, and the timber removed.

In the more modern plants, while the timber is being withdrawn at one end, a new charge is being introduced at the other end, thus saving time, and especially economizing in the cost of the treatment. These treating cylinders are built of boiler plate, are usually 6 feet in diameter

PLATE 3.—TIMBER-TREATING CYLINDER SHOWING ENTERING CHARGE.

and 110 feet long, and accommodate about 580 ties—the number being dependent upon the size of the latter. Two cylinders, one at Texarkana and the other at Beaumont, Texas, are 9.5 feet in diameter and 165 feet long, and 9 feet in diameter and 136 feet long, respectively. The cylinder at Beaumont holds 1860 ties at one charge.

Iron trucks with hop-like arms are loaded with ties, which are chained fast to the trucks in order to prevent floating while in the cylinder. These trucks are run into the cylinder on a track.

The entire treatment occupies from eight to twelve hours. This does not refer to the treatment of piling with creosote. The latter

takes from twenty-five to forty-eight hours, depending upon the amount injected.

I shall not refer to the history and gradual development of the various preservative processes, nor shall I give any of the details of nearly four hundred United States patents, although a reference to some of the patented processes would furnish entertainment. I propose to discuss briefly a few of the processes as carried out, on a large commercial scale, in the United States to-day.

Omitting various unimportant details, we may group the processes under three divisions involving:

1. The use of zinc chlorid, known as burnettizing.
2. The use of creosote.
3. The use of various modifications of zinc chlorid and creosote.

Burnettizing.

A 2.5 to a 4 per cent. solution of $ZnCl_2$ was and still is used. This process has had, in the past, the most extended use. On account of the fact that the zinc chlorid is leached out quite readily in wet sections, the treatment was somewhat modified. One of the noted modifications consisted in a preliminary treatment with $ZnCl_2$, then the removal of the $ZnCl_2$ solution from the cylinder, and the introduction of a solution of glue and tannin. The latter was said to form an "insoluble leather" on the outer cell-walls of the tie. This was known as the Wellhouse process, and had an extended use on the A. T. & S. F. R. R. It was abandoned by this road in 1898 for the reason that the added cost was not justified by the supposed increase in life of the tie.

The other modification of the Burnett process was the introduction of an emulsion of creosote with a solution of $ZnCl_2$. This has found wide and successful application in Germany (by Rütgers), and, of late years, an extended use near Chicago (by Chanute). It is quite efficient, and has the advantage of being less expensive than straight creosoting. The penetration of the emulsion is also much better than is the penetration when zinc chlorid or when creosote is used singly—equal amounts of both materials being considered. The Allardyce process consists of separate injections of zinc chlorid and of oil.

Creosoting.

Unquestionably the most efficient material in use to-day is creosote oil derived from coal tar. It is also the most expensive. It is the

TABLE A.—SHOWING RESULTS OF ANALYSES OF CREOSOTE OILS EXTRACTED FROM WELL PRESERVED TIMBERS.

Timbers Secured and Analyzed by Gellert Alleman.

(Published with the Permission of the Forest Service.)

Description.	Obtained From	Length of Service.	Pounds of Anhydrous Creosote Oil per Cubic Foot of Timber.	Analysis of Extracted Oils. Distillation of Extracted Oil, Percentage by Weight. To 205°.	205° to 245°.	245° to 270°.	270° to 320°.	320° to 420°.	Above 420°.	Total.	Per Cent. Solid Naphthalene Recovered from Distillates.	Per Cent. Solid Anthracene Oil Recovered from Distillates.	Tar Acids by Volume.	Variety of Wood.
Tie.	Glasgow and South Western Railway, Scotland.	16 years.	4.06	..	16.32	13.24	20.15	24.10	25.93	99.74	..	..	0.51	Pine.
Tie.	"	18 years.	9.24	..	9.37	18.17	27.54	21.38	23.01	99.47	..	..	0.36	Pine.
Tie.	"	18 years.	8.01	..	9.75	18.54	24.96	22.42	24.07	99.74	..	..	1.13	Pine.
Tie.	"	16 years.	8.29	..	7.08	12.45	16.68	40.84	22.52	99.57	..	..	0.74	Pine.
Tie.	"	42 years.	12.71	..	9.45	12.30	27.56	33.48	17.87	100.66	..	51.07	0.96	Baltic redwood.
Tie.	"	20 years as tie and 13 years as fence-post.	5.08	..	6.83	10.16	26.11	32.17	23.91	99.18	..	..	..	Baltic redwood.
Tie.	London and North Western Railway Co., England.	19 years.	14.07	..	17.78	11.88	21.26	14.64	34.01	99.57	..	35.14	0.26	Baltic redwood.
Tie.	"	19 years.	13.84	..	18.23	16.61	23.01	12.78	29.11	99.74	..	26.87	0.68	Baltic redwood.
Paving blocks.	North Eastern Railway Co., England.	20½ years.	17.19	..	20.13	10.27	12.18	27.46	29.78	99.82	21.46	57.03	1.19	Yellow pine.
Tie.	"	30 years.	7.41	..	15.44	7.44	15.68	44.96	16.14	99.66	..	..	0.37	Pine.
Paving blocks.	City Engineer, Hull Corporation, Hull, England.	11 years.	14.37	..	21.03	24.45	7.68	25.06	21.78	100.00	24.93	..	0.87	Yellow pine.
Tie.	Maryport and Carlisle Railway Co., England.	23 years.	5.17	..	10.59	12.61	28.56	20.32	27.87	99.95	..	..	0.62	..
Tie.	Highland Railway Co., Scotland.	20 years.	5.93	..	15.78	8.04	27.80	18.12	29.81	99.55	..	48.14	0.76	Scotch fir.
Tie.	"	20 years.	9.03	..	10.15	16.32	20.54	12.63	40.02	99.66	..	52.13	0.54	Scotch fir.
Tie.	"	22 years.	12.76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Railway Co., Scotland.													
Tie.	"	21 years.	8.19	..	18.24	12.16	28.92	22.76	17.35	99.43	..	..	0.21	Scotch fir.
Tie.	"	14 years.	..	..	..	..	..	..	..	..	..	..	..	Scotch fir.
Pile.	"	14 years.	7.21	0.47	7.65	8.03	17.58	38.88	27.97	100.58	..	53.04	1.23	Scotch fir.
Pile.	Clyde Navigation Trust, Glasgow.	46 years.	8.42	..	9.44	16.92	29.68	32.08	11.03	99.15	..	..	..	Red pine.
Pile.	"	46 years.	8.07	2.76	19.53	14.61	18.15	17.23	27.03	99.31	..	..	..	Red pine.
Pile.	"	46 years.	9.31	..	22.20	20.10	24.30	16.24	16.84	99.68	..	33.14	..	Red pine.
Pile.	Great Western Railway, Heath Division, England.	47 years.	7.68	..	19.92	17.58	20.62	14.48	27.11	99.71	..	32.15	0.78	Yellow pine.
Tie.	Clyde Navigation Trust, Glasgow.	22 years.	12.36	..	9.03	15.21	29.46	13.35	32.91	99.96	..	41.16	1.37	Pitch pine.
Tie.	"	16 years.	9.42	..	6.39	10.38	27.75	31.86	23.51	99.89	..	52.14	1.15	Baltic redwood.
Pile.	"	46 years.	12.61	..	16.87	12.15	13.25	25.37	32.30	99.94	..	54.42	1.07	Red pine.
Pile.	"	21 years.	9.06	..	13.56	10.52	20.34	31.24	23.92	99.58	..	..	1.78	Pitch pine.
Pile.	Norfolk Creosoting Co., Norfolk, Va.	11 years in Tampico Bay, Florida.	18.34	..	38.88	13.76	13.12	10.08	24.02	99.86	34.47	37.24	..	Loblolly pine.
Pile.	"	15 years in Santiago Harbor, Cuba.	19.12	..	51.50	12.35	3.74	11.61	21.03	100.23	48.62	34.15	..	Loblolly pine.
Pile.	"	20 years at Newport News, Virginia.	8.43	..	13.56	15.78	14.49	19.77	36.13	99.83	..	55.22	..	Loblolly pine.
Pile.	"	17 years at Newport News, Virginia.	13.21	..	19.07	12.39	12.32	17.58	38.14	99.50	18.96	43.71		Loblolly pine.
Tie.	E. B. Cushing, Southern Pacific Co., Houston, Tex.	22 years at Houston, Texas.	Center = 19.36 Under rail = 16.14	..	22.53	13.47	22.63	18.58	22.37	99.58	22.53	46.18		Loblolly pine.
Pile.	International Creosoting and Construction Co., Galveston, Texas.	29 years in Galveston Bay.	17.63	1.26	27.60	22.43	31.22	12.02	5.13	99.66	25.41	48.15	..	Loblolly pine.
Pile.	"	29 years in Galveston Bay.	17.08	2.18	31.06	18.21	36.04	8.17	4.13	99.79	28.14	41.12		Loblolly pine.
Paving blocks.	"	34 years in New Orleans, La.	18.81	0.48	26.61	32.06	17.52	8.47	14.42	99.56	..	50.67		Loblolly pine.
Paving blocks.	"	29 years at Galveston.	12.44	0.68	17.57	18.78	37.52	16.62	8.56	99.73	3.68	53.89		Loblolly pine.
Paving blocks.	"	9 years at Galveston.	54 = 6.07 55 = 5.46	9.62	14.41	19.27	41.74	11.23	3.40	99.67		.		Loblolly pine.
Conduit pipe.	Bell Telephone Co.	14 years in conduit at Philadelphia.	8.74	5.08	27.23	10.46	27.68	19.03	9.93	99.41	23.17	14.28	..	Pine.

only material which will effectually protect timbers submerged in certain ocean waters from the teredo or common ship worm. I am of the opinion that good straight creosote, for purely economic reasons, should not be used on ties, but should be reserved entirely for piling intended for marine work. The present consumption of creosote oil is growing to be enormous, and the prices are advancing accordingly.

The production of creosote oil in this country in 1905 amounted to about nine and one-half million gallons. To this must be added the importation of 7,750,531 gallons, making the total consumption of creosote oil in this country in 1905 about 16,363,000 gallons. In 1906 there were imported 13,235,007 gallons. This is almost double the amount imported the previous year, and four times the amount imported in 1904.

All creosote oils are not equally valuable—the higher boiling oils having proved to be most effectual. The high price of this commodity leads to frequent frauds on the part of the treating firm. Of twelve specimens which I cut from a consignment of piling guaranteed to contain sixteen pounds of oil to the cubic foot of timber, some of the samples contained less than three pounds, and none over seven pounds. Timbers intended to withstand the ravages of the teredo off the coast of Florida and in the Gulf of Mexico, as well as on the Pacific coast, should contain about eighteen to twenty pounds per cubic foot of a good quality of oil.

Reference must be made to a new and unique process of creosoting which has been lately introduced by the Santa Fe at its newly rebuilt plant at Somerville, Texas. A number of other treating plants in the West are either using or are contemplating the use of this new process. The process bears the name of Rüping—a German. The air-dried wood is introduced into the treating cylinder and first placed under a pressure of five atmospheres. The oil is then run in under a pressure of fifteen atmospheres. After the treatment the creosote is squeezed out of the cells by the compressed air first applied, leaving only a small amount of creosote on the fiber. The penetration is very thorough, and the amount of oil required is said to be about one-fourth that ordinarily used for penetration to the same extent. The cost of this method of creosoting is certainly reduced to less than one-half the cost of creosoting by the usual process, when the outer cell-walls are completely filled. Actual tests on a very large scale now being made by the Santa Fe will demonstrate the value of this process. A special creosote oil is required. It must be entirely liquid.

In order to determine the quality of the oils found in well preserved timbers which had been subjected to various kinds and degrees of service for a number of years, I secured samples of such timbers, the history of which is unquestioned, and analyzed the extracted oils.

Table A, pages 224 and 225, shows the results obtained.

A glance at this table will indicate that the "tar acids" have disappeared as such; that the high-boiling portions remain in the timber while the low-boiling portions have been removed; that both naphthalene and anthracene oils make up a large portion of the oil contained in well preserved piling, while in a number of cases the oils extracted from well preserved sleepers contained little, if any, naphthalene or anthracene. It is evident in these latter cases that naphthalene and anthracene were extracted from the creosote oils before they were used.

Life and Cost of Treatment.

The question of the life of a treated or an untreated tie depends entirely upon local conditions. In certain sections of Texas an untreated loblolly pine tie will not last a year. I have seen burnettized ties placed in this section, and, after three years of service, removed on account of decay. The life of the same timber in one section of the country may or may not be—and usually it is not—the same, when exposed to the climatic conditions incident to another section.

Records kept on 5,000,000 ties on the A. T. & S. F. prove that pine ties (long-leaf, short-leaf, and loblolly), when properly treated with $ZnCl_2$ and some with $ZnCl_2$ and glue, had respective lives of 10.18 years and 10.75 years. The zinc chlorid and glue treatment contributed to a slightly longer service.

In a test made on the western division of the Pittsburg, Fort Wayne, and Chicago Railway, it was found that white oak ties laid in rock ballast had a life of 10.17 years, and that hemlock treated by the zinc-tannin process, laid in the same kind of ballast, lasted 10.71 years.

In another section of this track is was determined that white oak ties laid in gravel ballast lasted 9.47 years, and that tamarack ties treated with zinc chlorid and tannin had, under the same conditions, a life of 8.84 years.

The C. R. I. & P. found that hemlock ties treated with $ZnCl_2$ and glue lasted 10.66 years.

Not including royalty on patents, profit, interest, or depreciation,

all of which vary widely at the various plants, the actual cost of treating a tie containing three cubic feet is about as follows:

Zinc chlorid	16 cents.
Zinc chlorid and creosote	27 cents.
Creosote, 10 pounds to the cubic foot	55 cents.

The cost of creosoted piling is much greater, in proportion, owing to the longer time required for a thorough penetration. For instance, a 60-foot pine pile would cost about $20 for thorough treatment; a 75-foot pile, with an 18-inch butt, would cost about $37 for an efficient treatment with a high-grade oil.

Economic Considerations.

A tie which has a long life is preferable because it adds greater safety and permanence to the road-bed. For these reasons a single tie would be preferable to two ties costing a like amount and whose combined life was equal to the single tie.

The questions involved in any comparison between the ultimate cost of treated and of untreated timber are more complex than is ordinarily credited. This feature of the problem belongs properly to the domain of railroad finance. Since the amounts expended must be renewed at the end of a given period, provided the maintenance is kept up, any comparison between the ultimate cost of treated and of untreated timbers must be resolved into a comparison between the annual charges made against these timbers. The features involved are the original cost, the length of life, the cost of renewal, and compound interest on the investment. The rate of interest is immaterial, since any comparison must be made at the same rate.

If it is admitted that a fair comparison can be made by consideration of the annual charges, if computed in the same manner, then, in order that the two kinds of timbers may be of equal value from a financial standpoint, the sum of such annual charges in the case of untreated timbers must be equal to the sum of the annual charges referred to the treated timber with which the comparison is made.*

Let C = original cost of tie;

n = life of tie in years;

A = annual payment, with compound interest, which, if placed aside, will amount to sufficient to replace (at cost of C) the tie at the end of n years;

r = rate of interest on initial cost.

*I am indebted to Professor John A. Miller, of Swarthmore College, for the mathematical statement of the following facts.

We make a payment of C when tie is installed. We make a second payment of C at the end of n years. The present worth of this second payment is $\frac{C}{(1.0r)^n}$. We make a third payment of C at the end of $2n$ years. The present worth of this third payment is $\frac{C}{(1.0r)^{2n}}$; then the total present worth of the investments will be equal to

$$C + \frac{C}{(1.0r)^n} + \frac{C}{(1.0r)^{2n}} + \ldots$$

Suppose the annual payment, A, is made at the end of each year. The present worth of these payments is as follows:

For the first payment, $\frac{A}{1.0r}$.

For the second payment, $\frac{A}{(1.0r)^2}$.

For the third payment, $\frac{A}{(1.0r)^3}$.

For the fourth payment, $\frac{A}{(1.0r)^4}$.

. . . .

For the nth payment, $\frac{A}{(1.0r)^n}$,

which annual payments represent the present worth of the tie during its life of n years.

When the tie is replaced, after n years, the present worth of the payments on this replaced tie will be:

For the $n + 1$st payment, $\frac{A}{(1.0r)^{n+1}}$.

. . . .

. . . .

For the $2n$th payment, $\frac{A}{(1.0r)^{2n}}$,

which represents the present worth of the payments to be made on the second tie.

When this tie is replaced by a third tie at the end of $2n$ years, the present worth of the annual payments against this third tie are:

For the $2n + 1$st payment, $\frac{A}{(1.0r)^{2n+1}}$.

. . . .

. . . .

For the $3n$th payment, $\frac{A}{(1.0r)^{3n}}$.

The present worth of the cost (C) will be equal to the present worth of the annual payments charged up against these ties as long as the series is continued, *i. e.*,

$$C + \frac{C}{(1.0r)^n} + \frac{C}{(1.0r)^{2n}} + \cdots = \frac{A}{(1.0r)} + \frac{A}{(1.0r)^2} + \cdots \frac{A}{(1.0r)^n}$$
$$+ \frac{A}{(1.0r)^{n+1}} + \frac{A}{(1.0r)^{n+2}} + \cdots \frac{A}{(1.0r)^{2n}}$$
$$+ \frac{A}{(1.0r)^{2n+1}} + \frac{A}{(1.0r)^{2n+2}} + \cdots \frac{A}{(1.0r)^{3n}}$$

The sum of the left-hand side is

$$\frac{C}{1 - \frac{1}{(1.0r)^n}} = \frac{C(1.0r)^n}{(1.0r)^n - 1}$$

The sum of the right-hand side is $\frac{A}{.0r}$; or,

$$A = \frac{.0r \times C \times (1.0r)^n}{(1.0r)^n - 1}$$

Suppose a tie costs eighty cents and lasts twelve years. Suppose the rate of interest to be paid on the money is 5 per cent., then the annual charge (A) will be

$$\frac{.05 \times 80 \times (1.05)^{12}}{(1.05)^{12} - 1} = \frac{.05 \times 80 \times 1.7958}{1.7958 - 1} = 9.02$$

In case the rate of interest to be paid on the money is 4 per cent., then the annual charge (A) will be

$$\frac{.04 \times 80 \times (1.04)^{12}}{(1.04)^{12} - 1} = \frac{.04 \times 80 \times 1.6010}{1.6010 - 1} = 8.53$$

The annual charge, A', against renewals must also be considered. No money is paid out until the tie is renewed at the end of n years. Annual charge (A') against such renewal would be

$$A' = \frac{C' \times .0r}{(1.0r)^n - 1}$$

in which C' is the cost of renewal, and r is the rate of interest.

The annual charge against a tie costing 80 cents and lasting twelve years, assuming the investment is on interest at 4 per cent., is 8.53 cents. If it costs 20 cents to relay this tie, we should add the annual charge of 1.33 cents to the above amount, inasmuch as this represents the annuity, which, if placed aside yearly for twelve years, will equal the amount necessary to relay this tie. The total annual charge against the tie in question would, therefore, be 8.53 + 1.33 = 9.86 cents.

For convenience in making a comparison of the relative annual charges against timbers of known cost and life, I have prepared Tables B and C, in which these various charges are stated. The interest in both tables is compounded at 4 per cent.*

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* Professor B. E. Fernow published a similar table, compounding the interest at 5 per cent., in Bulletin No. 4 of the Forestry Division.

TABLE B.—SHOWING ANNUAL CHARGE AGAINST TIE, IF ORIGINAL COST AND THE LIFE OF THE TIE ARE KNOWN.

The Interest on the Original Cost is Compounded at 4 Per Cent.

Original Cost of Tie.	Life of Tie, in Years.																	
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
20 cents	7.21	5.51	4.50	3.82	3.33	2.97	2.69	2.47	2.28	2.13	2.00	1.90	1.80	1.72	1.65	1.58	1.52	1.47
25 cents	9.01	6.87	5.62	4.77	4.17	3.71	3.37	3.08	2.85	2.66	2.50	2.38	2.25	2.15	2.06	1.98	1.90	1.84
30 cents	10.81	8.26	6.74	5.72	5.00	4.46	4.04	3.70	3.43	3.20	3.01	2.85	2.70	2.57	2.47	2.37	2.28	2.21
35 cents	12.61	9.64	7.87	6.68	5.83	5.20	4.71	4.32	4.00	3.73	3.51	3.33	3.15	3.00	2.88	2.77	2.66	2.57
40 cents	14.41	11.02	8.99	7.63	6.66	5.94	5.38	4.93	4.57	4.26	4.01	3.80	3.60	3.43	3.29	3.16	3.05	2.94
45 cents	16.21	12.39	10.11	8.59	7.50	6.69	6.06	5.55	5.14	4.80	4.51	4.28	4.05	3.86	3.70	3.56	3.43	3.31
50 cents	18.01	13.77	11.24	9.54	8.33	7.43	6.73	6.17	5.71	5.33	5.01	4.75	4.50	4.29	4.11	3.95	3.81	3.68
55 cents	19.81	15.15	12.36	10.49	9.16	8.17	7.40	6.79	6.28	5.86	5.51	5.23	4.95	4.72	4.52	4.35	4.19	4.05
60 cents	21.61	16.52	13.49	11.45	10.00	8.91	8.08	7.40	6.85	6.40	6.01	5.70	5.40	5.15	4.93	4.74	4.57	4.41
65 cents	23.42	17.90	14.61	12.40	10.83	9.66	8.75	8.02	7.42	6.93	6.51	6.18	5.85	5.58	5.34	5.14	4.95	4.78
70 cents	25.22	19.28	15.73	13.36	11.66	10.40	9.42	8.64	7.99	7.46	7.01	6.65	6.30	6.01	5.75	5.53	5.33	5.15
75 cents	27.02	20.66	16.86	14.31	12.50	11.14	10.10	9.25	8.56	7.99	7.51	7.13	6.75	6.44	6.17	5.93	5.71	5.52
80 cents	28.82	22.03	17.98	15.26	13.33	11.89	10.77	9.87	9.14	8.53	8.02	7.60	7.20	6.86	6.58	6.32	6.09	5.79
85 cents	30.62	23.41	19.11	16.22	14.16	12.63	11.44	10.49	9.71	9.06	8.52	8.08	7.65	7.29	6.69	6.72	6.47	6.25
90 cents	32.42	24.79	20.23	17.17	14.99	13.37	12.11	11.10	10.28	9.59	9.02	8.55	8.10	7.71	7.40	7.11	6.85	6.62
95 cents	34.22	26.16	21.35	18.13	15.83	14.12	12.79	11.72	10.85	10.13	9.52	9.03	8.55	8.41	7.81	7.51	7.23	6.99
100 cents	36.02	27.54	22.48	19.08	16.66	14.86	13.46	12.33	11.42	10.66	10.02	9.50	9.00	8.58	8.22	7.90	7.61	7.36
For each additional 5 cents to the cost add	1.801	1.377	1.124	0.954	0.833	0.743	0.673	0.617	0.571	0.539	0.501	0.475	0.450	0.429	0.411	0.395	0.381	0.368

TABLE C.—SHOWING ANNUAL CHARGE AGAINST TIE FOR RELAYING, IF COST OF RELAYING AND TIME ARE KNOWN.

The Interest on Cost of Relaying is Compounded at 4 Per Cent.

Cost of Relaying.	Time of Relaying, in Years.																	
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Cents.	Cents.	Cents.	Cents	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
10 cents	3.20	2.35	1.85	1.51	1.27	1.08	.95	.83	.74	.67	.60	.55	.50	.46	.42	.39	.36	.34
15 cents	4.80	3.53	2.77	2.26	1.90	1.62	1.42	1.25	1.11	1.00	.90	.82	.75	.69	.63	.58	.54	.50
20 cents	6.41	4.71	3.69	3.02	2.53	2.16	1.89	1.66	1.48	1.33	1.20	1.09	1.00	.92	.84	.78	.72	.67
25 cents	8.01	5.89	4.62	3.77	3.17	2.71	2.36	2.08	1.85	1.66	1.50	1.37	1.25	1.15	1.06	.97	.90	.84
For each additional cent, add	.320	.235	.185	.151	.127	.108	.095	.083	.074	.067	.060	.055	.050	.046	.042	.039	.036	.034

For instance, a tie costing 35 cents and lasting seven years has an annual charge against it of 5.83 cents (not counting renewal). This is practically the same annual charge as made against a 55 cent tie lasting twelve years, or a 65 cent tie lasting 15 years.

A 45 cent tie lasting eleven years has the same annual charge against it as a 65 cent tie lasting eighteen years—the annual charge in both cases being 5.14 cents.

However, assuming that the tie cost 20 cents to relay, the relaying annual charge against the eleven-year-old tie would be 1.48 cents, making a total annual charge against this tie of 6.62 cents. The annual charge for relaying, against the eighteen-year-old tie is 0.78 cents, making a total annual charge against this tie of 5.92 cents. The eighteen-year tie is, in reality, cheaper than the eleven-year tie.

Suppose we buy a tie for 45 cents, and the life of this tie is 6 years. How much can we expend in preservative treatment if, by so doing, the life is extended to fourteen years? The annual charge against the untreated tie is 8.59 cents. To this must be added the annual charge for renewal of 3.02 cents, provided it costs 20 cents to relay, making a total annual charge of 11.61 cents. If 50 cents was added in preservatives, this tie would have to last about twelve years—the annual charge against the 95 cent tie, including renewal, being 11.46 cents.

Media is about ten miles distant from the 49th Street Station. The track is doubled. Not counting side tracks, there are approximately 52,000 ties in this stretch. These oak ties cannot be replaced for less than 85 cents. The average life on this division is about nine years. The annual charge, including renewals at 20 cents, would be 13.33 cents per tie, or $6921 for the track. I think I am conservative in stating that a 45 cent pine tie subjected to a 30 cent treatment will last at least ten years on this track. This would mean an annual charge, including renewal, of 10.91 cents per tie, or $5671 for the track. These figures indicate the possibility of saving an annual charge of $1250 on this track, which at 4 per cent. represents dividends on $31,250.

One important consideration in this connection must not be lost sight of. The mechanical wear of the tie must always be carefully considered. Of course it is not a paying proposition to add to the cost of a tie by preservative processes to such an extent that the tie is preserved from decay for years in excess of its mechanical life.

In a confidential report, privately circulated by one of our great railway systems, the statement was made that if a treated tie lasted twice as long as an untreated tie, the cost of the former might be 30.53 per

cent. greater than the cost of the untreated tie—the real expenditure, at the end of the life of the treated tie (in this case assumed to be twenty years) being the same. In illustration of this claim the following example was given:

The cost of two ties costing 55 cents each and 10 cents to lay, lasting ten years each, is:

Cost of first tie, 55 + 10	$0.65
Ten annuities for first renewal at .05168	.517
Twenty annuities for second renewal at .03929	.393
Interest on first cost for twenty years at 5 per cent	.65
Total cost for twenty years	$2.21

The cost of the assumed treated tie was given as follows:

Cost of tie	$0.35	
Cost of treatment	.3984	
Total cost of treated tie in track, including cost of laying,		.8484
Annuities which will aggregate .8484, in twenty years,		.5128
Interest on first cost for twenty years		.8484
Total cost for twenty years		$2.2096

Here we have a mixture of annuities and interest charges. The two cannot be confounded. Annuities should include interest charges. If we wish to consider the cost on the basis of principle and interest alone, then, at the end of twenty years, the first tie would be worth the first cost, 65 cents, and interest on the first cost for twenty years at 5 per cent., or $1.30. The second tie would be worth, at the end of ten years, its original cost of 65 cents and the interest on this for ten years, or $0.975. The total cost of these two ties, so considered, at the end of twenty years, would be $2.275.

If we consider the cost of the treated tie at the end of twenty years, making similar calculations, involving the original cost of $0.8484 and interest on this cost, for twenty years, at 5 per cent., we find that the cost of the treated tie is $1.6968.

If, on the other hand, we make the comparison on the basis of annuities at 5 per cent., we find that the annual charge against a 65 cent tie, lasting ten years, is 8.41 cents. In order to keep these two ties in the track during a period of twenty years we must make an annual outlay of 8.41 cents.

If we compare the annual charge against the 85 cent treated tie lasting twenty years, we find that this amounts to but 6.81 cents. This involves an annual saving of $31.60 per mile of single track, in favor of the treated tie.

Renewed interest has recently been displayed in connection with the use of metal ties. The annual charge against a metal tie lasting thirty years and costing $2.00, figuring the interest at 5 per cent., is 12.99 cents. This is about the same as the charge against a 75 cent tie lasting seven years. But this exception must be made: the metal tie, at the end of thirty years, is worth something as old iron; the wooden tie, when worn out, is useless.

Mechanical Injury Caused by Treatment.

The question is often asked: Does the chemical treatment of timber injure it from a mechanical standpoint? Timber is frequently injured by excessive steaming or by high temperature either during the steaming process or during the injection of the preservative. I recall that some of the creosoted ties placed in the experimental track in Texas broke in half in the track after a few months' service. Some of these ties were so brittle that they broke on being thrown from the car to the ground. They had been subjected to an excessive temperature during the steaming process and also during the injection of creosote. I am of the opinion that the action of steam on wood produces a slow hydrolysis of certain of the celluloses composing the lining of the cells. In case the steaming process is carried on for a long time, or in case the steam is under high pressure, the wood will be modified, and the modification is dependent upon the intensity of the action and its duration. In the case of treatment with creosote it is to be noted that the tar acids, especially the three cresols, have a marked solvent action on the lining of the cell-walls, provided these tar acids come in contact with the wood at a temperature much beyond the boiling-point of water. In the case of the treatment of piling which contains twenty pounds of creosote, and which must necessarily be kept in contact with creosote oil for about eighteen hours, the temperature of the cylinder is kept at about 212° F.* A higher temperature, for this length of time, produces marked mechanical injury to the timber.

Recent tests made by Professor W. K. Hatt show that timber subjected to steam, under pressure, shows a loss in strength, and that such loss is a function of the steam pressure and the duration of such treatment.

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* Many creosoters keep the temperature about 180° F. Treatment by the Rüping process is done at 130° F.

Reducing all the figures to percentages, the following results (for loblolly pine) were obtained:

Strength of unsteamed tie	100.
Strength of tie steamed 4 hours at 10 pounds	89.
" " " 4 " 20 "	84.
" " " 4 " 30 "	75.
" " " 4 " 40 "	76.
" " " 4 " 50 "	68.
" " " 4 " 100 "	41.

These figures have been corrected in order that the tests may be comparable at the same degree of moisture.

Additional tests showed that steamed ties which had been subsequently treated with zinc chlorid were no weaker under static load when compared with the strength of steamed ties. Ties so treated, when subjected to impact loading, were found to have less strength than ties which had been simply steamed.

Ties which were steamed and afterward creosoted were no weaker than ties which had been simply steamed.

Ties which were treated by zinc chlorid and by creosote without previously steaming show conflicting results in the case of treatment with zinc chlorid, and a slight gain in strength in the case of treatment by creosote. The latter gain in strength is unquestionably due to a partial seasoning of the timber due to the treatment.

Professor Hatt also determined that the power necessary to withdraw the ordinary spike from the natural tie is about the same as is required to withdraw the spike from a tie steamed for four hours at thirty pounds. It is a curious fact that steaming for four hours, at less than thirty pounds, increases the holding power, while steaming for more than four hours at twenty pounds decreases it. Ties which are first steamed, and then treated with zinc chlorid or with creosote, have even less holding power than ties which have been subjected to no process save that of steaming.

These results go to show that whatever injury is done in the treating process results from the action of the steam on the wood, and cannot be accounted for in consequence of the subsequent injection of various preservatives.

That a high degree of steaming is injurious to wood is unquestioned. The degree at which injury will result depends upon the character of the wood, the temperature to which it is heated, and the duration of the process. In the case of loblolly pine, injury will result if it is steamed

for a longer period than four hours at thirty pounds pressure, or a longer period than six hours at a pressure of twenty pounds.

A full discussion of the results of the work of Professor Hatt will be found in Circular 39 of the Forest Service.

Notwithstanding all the work done by individuals and by the Government within the last ten years, little has been added to our knowledge concerning actual improvements on old methods of timber preservation, or the introduction of new, cheap, and efficient substitutes for the older methods. With the single exception of the Rüping process, no radical change in timber preservation has been witnessed within the last ten years. Many experiments have been conducted, but they have never reached the practical stage. Investigations along new lines in timber preservation require the services of the engineer, the bacteriologist, the botanist, and the chemist. The latter must be familiar with the chemistry of the celluloses to be of much value.

Frequently, in the face of the results of experiments, we are required to change our views on what, from a theoretical standpoint, seemed to be a valuable process. In this connection, I must mention some facts in regard to two processes which looked promising, but resulted in failure—the first from a very peculiar cause.

This was a modification of the old kyanizing process, consisting of the use of a mixture of corrosive sublimate and arsenious oxid. Workmen using it suffered from salivation. The Memphis and Charleston R. R. paid $50,000 for the privilege of using it. They put down ten miles of track. The mixture effloresced on the ties, the cattle licked up the material, and died all along the track; the farmers took a hand in the affair and made the railroad remove and burn every tie so treated. This process has never since been used for the treatment of ties, and has been practically abandoned.

The other method was the process of Haesselmann—a German architect. I think he caused more ill-will among chemists and engineers than any other individual ever connected with wood preserving. His treatment—which, by the way, was made on green timbers—consisted in boiling the timbers in a solution of the double sulphates of iron and copper, aluminum sulphate, and the mineral kainit ($Al_2(SO_4)_3.KCl.$-$3H_2O$), obtained from Stassfurt. The system had the advantages of being cheap (8 to 10 cents per tie all told), of being applicable to green timbers, of forming insoluble compounds with the wood, and the very great advantage in the fact that the ties would season in a few hours

after treatment, and could be shipped from the cylinder to the point at which they were to be used. The penetration, even in the hard resinous heart pines, reached the center in about four hours, and no previous steaming was required. It was stated that distinct salts of cellulose were formed, and that they had decided antiseptic properties. If ties were cut in two and a solution of $K_3Fe(CN)_6$ applied, no blue color was noticed. If, however, a few drops of HCl were added to the other section of the same tie, and then $K_3Fe(CN)_6$ added, a test for ferrous iron was obtained—clear proof that an insoluble compound of iron was introduced or formed by the treatment. After a rather lengthy investigation, I found that the internal walls were simply mordanted with $Al_2O_3 + Fe_2O_3$. It seldom happened that a trace of Cu was found—nearly all of the Cu having been deposited on the internal part of the iron cylinder. The cylinders at Sheridan, Wyoming, were badly injured by treating 60,000 ties with this process. This was probably due to the fact that free H_2SO_4 was found present in the $Al_2(SO_4)_3$ used. About 1200 ties were treated with this material at Somerville in 1898. Some of the ties have shown good service. The process has since been abandoned.

I am convinced that the formation of an insoluble compound in the wood will not attain the desired end. If you swallow a toxic dose of $HgCl_2$ it will probably kill you, unless some one furnishes an antidote in the shape of egg albumin, which forms an insoluble product with the corrosive sublimate, thus rendering the latter harmless to your system. I believe that the proper salt for timber preservation is one that is slightly soluble—just so soluble that it will form toxic doses for organisms of decay, thus checking their development. A *cheap* and *efficient* compound is still to be found.

Mr. Alleman (by Letter).—The interest displayed regarding the action of the ship worm leads me to give a more exact account than was possible in the time assigned.

Timbers which are submerged in ocean water seldom deteriorate from the ordinary organisms which cause decay, but are subjected to injury from other sources. Three varieties of ship worms, *Teredo navalis, Teredo norvegica,* and *Xylotrya fimbriata,* are extremely destructive in certain localities along the American coast. Considerable injury is also done in some sections by the *Limnoria* and the *Cherula.* The ship worms are mollusks, and form galleries underneath the surface of the timber and completely riddle it. The *Limnoria* and the *Cherula* are crustacean isopods and attack the timber on the out-

side, frequently cutting piling in two. These isopods seem to be equally prolific and correspondingly destructive in cold or warm waters.

The rate of increase among ship worms is almost beyond belief. Jeffreys calculated that one medium-sized female *Teredo navalis* contained 1,900,000 eggs, while Sigerfoos found that a female *Xylotrya fimbriata*, four feet in length, obtained at Beaufort, N. C., contained over 100,000.000 eggs. Under favorable environment, a ship worm

Plate 4.—Action of Teredo on Untreated Timber. Sections of Two Piles in Middle Row Were Cut from Properly Creosoted Timber Placed in Havana Harbor. These Were not Attacked by Teredo.

thirty-six days old attains a length of four inches and is then able to produce a new generation. Specimens of *Teredo norvegica* and *Xylotrya fimbriata* four feet in length and seven-eighths of an inch thick are abundant along the Atlantic coast from Newport News southward. On the Florida coast, certain localities in the Gulf of Mexico, and along the coast of California these same specimens attain a length of six feet and are about one inch in diameter. The ship worm seldom lives over two years. On account of their vast numbers and great size,

the *Teredo norvegica* and the *Xylotrya fimbriata* are almost entirely responsible for the great destruction done to submerged timbers along our southern coast. Sigerfoos observed that unprotected timbers placed in the waters at Beaufort, N. C., were completely honeycombed in five weeks.

It is extremely difficult to distinguish the *Teredo* from the *Xylotrya* by means of the head alone, but this can readily be done by reference

PLATE 5.—SMALL PIN-LIKE HOLES INDICATE WHERE TEREDO ENTERED WHEN SMALL. CONNECTION IS ALWAYS MAINTAINED WITH THE OUTSIDE THROUGH THESE SMALL OPENINGS.

to the pallets. The *Teredo* and the *Xylotrya* do not eat the wood, but live on infusoria obtained in it. The wood passes into one of the siphons in the shape of a very fine powder, and, on contraction of this siphon, it is thrown out. After entering the wood through a very small opening, the *Teredo* must hold, through its siphon, communication with the outside, in order to obtain its supply of water, without which it cannot live. The body of the *Teredo* is a gelatinous-looking, slimy mass, and it has the power of exuding a calcareous sub-

Plate 6.—Calcareous Lining of Teredo Galleries. The Wood Has Decayed, Leaving Portions of the Lining Intact.

stance, which hardens and forms the internal lining of the gallery in the wood. This lining is usually from .5 to 2 mm. thick. It is a curious fact that when the *Teredo* passes through rotten wood, it immediately exudes more of this calcareous material, and makes a much thicker lining than under ordinary conditions. The *Teredo* never crosses the burrow of his neighbor, and avoids knots, preferring to pass around them. The statement that some woods are not attacked by the *Teredo*

Plate 7.—Three Small Pieces Show Action of Teredo on Ebony, at St. Thomas, W. I. Large Piece Shows Action of Xylotrya on Fir in San Francisco Harbor.

lacks confirmation. The method by which the *Teredo* and the *Xylotrya* perforate the wood has been accounted for by various writers differently, but it is generally conceded that the account given by the Dutch Commission, which made a very thorough study of the *Teredo navalis*, is most worthy of credence. The account, together with the plates published by the Dutch Commission, is herewith appended. (Archives Neerlandaeses des Sciences, Tome 1, 1866, p. 1 to 43: E. H. von Baumhauer, "Sur le Taret et les moyens de preserver le bois de ses degets.")

"The shell is composed of two valves of equal size, which are *not*

fastened together. The valves are held in place by a fold of the mantle in the form of an arc (Fig. 4, *b*, Plate 8), which encircles them posteriorly. Moreover, the posterior part of the mantle has a prolongation (Fig. 4, *a*, and Fig. 6, *a*) which covers, to a certain extent, the dorsal side of the valves, and extends on each side to their margin, forming two lobes (Fig. 4, *c*, and Fig. 6, *b*), which nevertheless do not adhere to the shell; by this mode of union the relative position of the valves is maintained. With other bivalve mollusks, which do not perforate, this relation is firmly fixed by a hinge; but, with the *Teredo*, the valves have a certain play, which allows a slight displacement in their relative positions. The valves are, moreover, connected by two adductor muscles, which we will soon examine more closely.

"The shell presents, even when the valves are brought closely together, three large openings.

"The first, on the dorsal face (Fig. 8), is composed in part by a pallial prolongation, a continuation of which is introduced by this opening into the interior of the shell, in part by the small adductor muscle.

"The second opening is posterior (Fig. 7, *a*), and serves to open a passage to the internal organs contained in the cavity of the mantle.

"Finally, the third, placed obliquely in front (Fig. 5, *aa*, Fig. 7, *a*), is the largest, and remains always gaping open to allow the food to pass out (Fig. 5, *b*).

"Each of these valves, which form the shell, is formed of three parts, viz.:

"1. A posterior part (Fig. 8, *f*; Fig. 9, *f*; Fig. 10, *f*), which we can call the neck part; this posterior is the least arched, and thinner than the rest of the shell: its posterior edge is embraced by the folds of the mantle, which we have already mentioned, and thus the mantle is solidly attached to the shell.

"2. The middle part (Fig. 8, *b*; Fig. 9, *b*; Fig. 10, *b*), which is the largest, is strongly arched, and presents, when seen from the side, the form of a half moon; its ventral portion is a little more pointed, curved inwardly, and terminated by a small swelling or tubercle (Fig. 7, *b′*; Fig. 10, *b′*), which, when the shell is closed, comes in contact with the similar tubercle on the opposite valve.

"3. The anterior part, which is a continuation of the upper portion of the preceding part, and is more or less spiral in form (Fig. 9, *c*; Fig. 10, *c*; Fig. 8, *cc*; Fig. 7, *cc*), and its edge makes, when seen from the side (Fig. 6) an angle of a little more than 90 degrees with the free edge

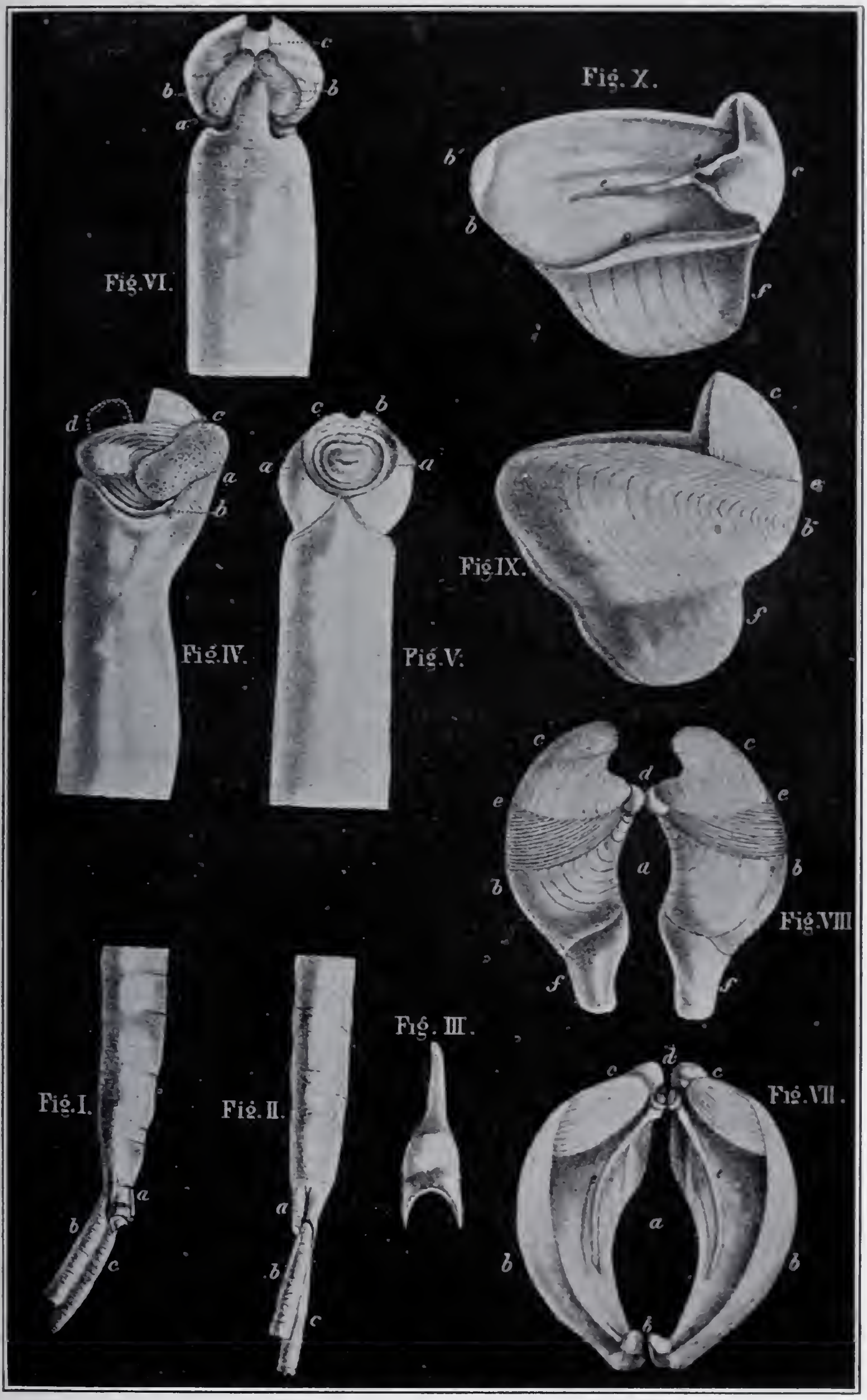

PLATE 8.—AFTER VON BAUMHAUER.

of the middle part. The limit of these two parts is marked by a zig-zag line, which resembles a sort of suture (Fig. 8, *e*, Fig. 9, *ee*). This part of the shell curves backward and inward, and there terminates in a small rounded tubercle (Fig. 7, *d*, Fig. 8, *d*, Fig. 10, *d*), situated opposite the corresponding tubercle of the other valve.

"This point is the axis of rotation of the two valves, that is to say when the shell opens or closes the tubercles retain their relative positions, while all other portions of the valves describe about them an arc of circle more or less large.

"On each of these tubercles is a short, pointed projection, on which are implanted at about a right angle two other large projections, which extend into the interior of the shell a third of half its length (Fig. 7, *ee*; Fig. 10, *e*). These projections are slightly curved and flattened; they penetrate among the soft parts, so that their inner face reposes upon the visceral mass; their outer face comes in contact with the thin lining or mantle, which covers the interior of the valves and extends to their extreme edge.

"Examining the shell with a magnifying glass, one sees (Fig. 1, Plate 9) a large number of curved lines of growth, parallel, as is usual, with the free margin of the shell; a closer examination shows that those lines differ in each of the three parts of the valve, although in fact they form a continuous whole.

"On the back of the neck of the valve (Fig. 1, Plate 9), the lines seem to be simply curved lines without any especial peculiarities. This is equally true of those on the posterior and largest portion of the middle part of the shell (Fig. 1, *b*); they seem to be only linear thicknesses; yet, between each pair of the strongest lines, which are the lines of growth, properly so called, one discovers a multitude of others, much finer, which follow the same direction. Here (Fig. 1, *ee*), the lines of growth form partitions between as many rows of small, sharp, wedge-shaped teeth. Each of these teeth has two rectangular faces on either side of two small triangular faces inclined toward each other (Fig. 2); its cutting edge is placed in the direction of the axis of the animal.

"The size of those small teeth varies according to the position they occupy: those which are in the vicinity of the hinge border are the smallest, those which are on the outer edge are the largest. And, as the part of the shell which is nearest the hinge is the earliest formed, in fact the only portion which exists at a very early period, it follows that the average dimension of the teeth increases with the size of the

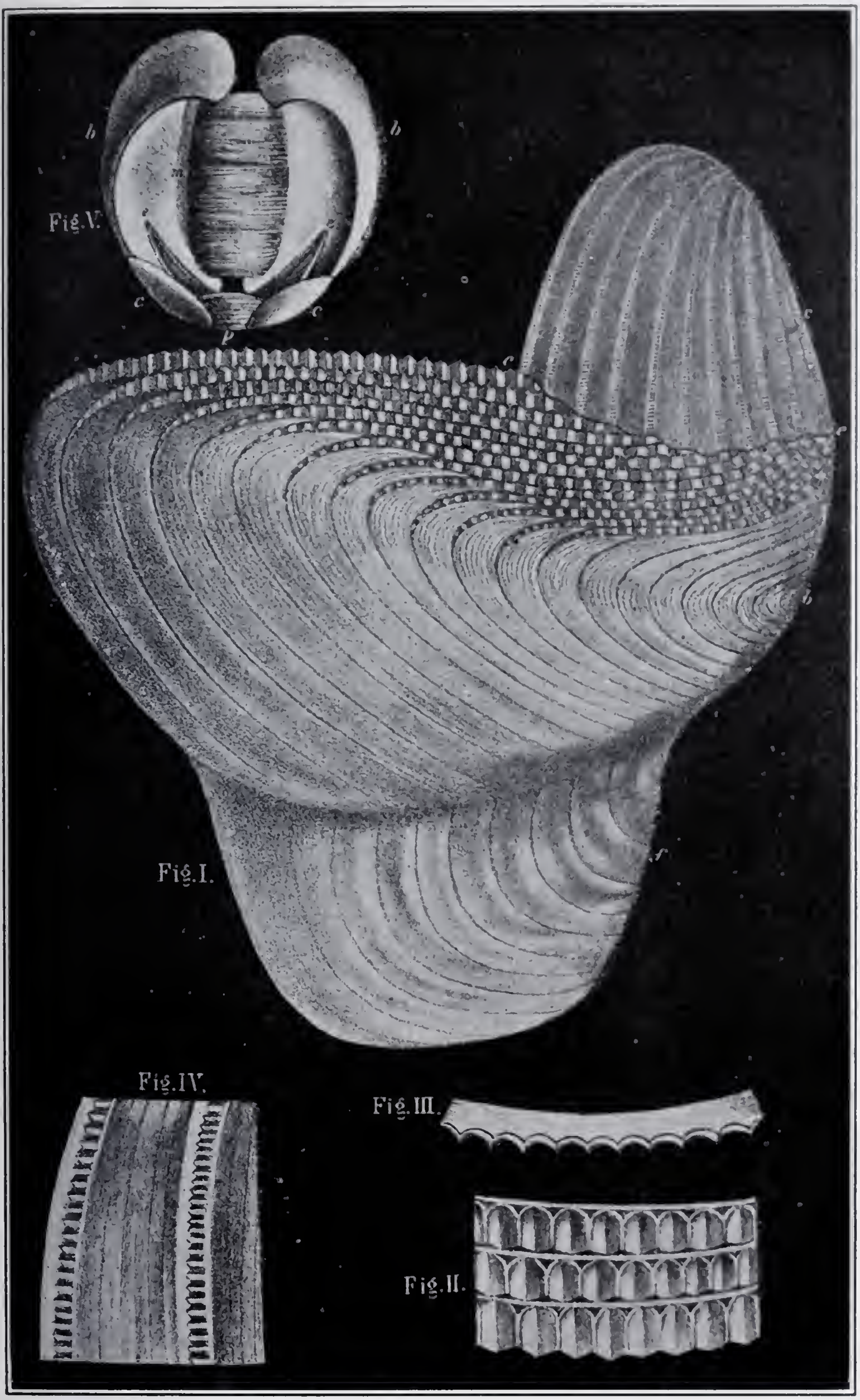

Plate 9.—After von Baumhauer.

shell, that is to say, with the growth of the animal. On a shell, for instance, of $7\frac{1}{2}$ millim. in its largest dimension, where the total number of rows of teeth reaches 41, the width of each row near the hinge part is 52 microns ($\frac{1}{19}$ millim.), and the size of each compartment occupied by a tooth is 28 microns ($\frac{1}{36}$ millim.), while the same measures, taken on the outer edge of the valve, give 145 and 45 microns ($\frac{1}{7}$ and $\frac{1}{22}$ millim.). At this last point the small, wedge-shaped teeth rise to a height of 32 microns ($\frac{1}{33}$ millim.) above their common support. On an average, there are in each row about 100 teeth, and consequently more than 4,000 on each valve, and more than 8,000 on the two valves together.

"The anterior part, in the form of a spoon, has a similar structure, but still more delicate. The lines of growth form an angle of a little more than 90° with those of the middle part, of which they are a continuation. They appear like small projecting ribs, the outer edges of which are cut in the form of small teeth pressed one against the other (Fig. 1, *c*). These denticles are also in form of wedges; their cutting surfaces are perpendicular to the axis of the animal, and consequently form a right angle with the cutting surfaces of the teeth of the middle part of the shell. But they are much smaller than the latter; their width is only 10 to 15 microns ($\frac{1}{100}$ to $\frac{1}{66}$ millim.). Their number is also more considerable, even although that part of the shell is less fully developed than the rest.

"On the same shell of $7\frac{1}{2}$ millim. diameter, the number of these denticles is, on an average, 250 on each rib, which makes 10,250 on the 41 ribs, and 20,500 on the two valves.

"We should also point out the fact that this spiral part of the shell is evidently composed of more solid matter than the rest of the shell. It has more lustre, and the look of porcelain, and its surface between the ribs is smooth and glossy.

. . . .

"Finally the teredo has also a muscular organ, without which it would be impossible for him to pierce his galleries. It is the part known as the foot, which has the power of projecting outside between the anterior opening of the valves (Fig. 5, *b*). This foot has the power of extension and retraction, and terminates at the end with a suction-disk, by the aid of which the animal can attach itself to the wood.

. . . .

"The foot remains fixed in the same spot a very short time only. The form of the end of the cavity, that of a regularly rounded basin, suffices to prove that the valves of the shell are placed every instant

in contact with a different spot. The foot displaces itself, little by little, so as to give a rotating movement to the shell, and at the same time to all that part of the body beyond the shell, even as far as the pallets. When the torsion thus produced becomes excessive, the foot loosens its hold, and the body returns to its former position. Thus, then, the rotary movements remarked by some observers, far from being the cause, should be considered rather the effect; they are only the shifting of position of the animal, and nothing more.

"The teredo does not bore out his galleries, but he hollows them out with an action analogous to that of a file, by means of the thousands of cutting teeth with which its valves are armed. If the teeth do not break away rapidly, it is due to their wedge-like form and to the oblique direction of the planes which bound each of these wedges. Moreover, as the animal grows, new rows of teeth are formed, so that the rows which have served in youth are no longer of any use in more advanced age; they are principally the outer rows of teeth, the last formed, which do the work."

DISCUSSION.

Wm. C. Furber.—I was hoping Professor Alleman was going to say something about the nature of creosote oils. In my practice I have used what is known commercially as "dead oil of tar." I think it costs about 15 cents a gallon by the barrel. It is a very light oil and seems to be very volatile. Whether or not it is the proper material to use for creosoting is, of course, for chemists to say. I should like to know more about the qualities of creosote oils.

I should also like to ask if there is a specification by which we can tell when we get the proper oil. There is the Avenarius Carbolineum, sold by a New York firm, which has a high boiling point. I do not know whether these are the proper oils to use or not.

E. M. Nichols.—I would like to have explained the exact scientific nature by which this preservation is obtained; whether it is a preventive of bacteriological growth in the wood, or whether it would tend to prevent disintegration from other sources.

I have failed to find in this discussion any particular reference to the longevity of ties used in the great railroads of the northwest. Twenty years ago, while connected with the Rock Island Railroad, I had under my charge a lot of treated hemlock ties which had been in use for sixteen years. There was a stretch of about one and one-half miles of road laid with these ties, and probably 50 per cent. of them still remain in their original places. They were then taking out a good many as samples. The most of these ties, as I understood from the records, were treated by the burnettized process. Some had been treated by coal tars, but my impression now is that the simple burnettized tie showed the longer life of the two, from the fact that it was harder and the mechanical effect of the rails was less.

W. F. Ballinger.—I would like to know whether there is any value to be attached to coating the outside of timbers with any kind of creosote oil, provided these timbers are to be buried, say, in a floor that is built up from the ground. It has been our practice where we have a floor about level with the ground, to lay on the ground a coal tar composition mixed with stone or slag, making it about three inches thick, and then put the sleepers on these pieces that have been treated with creosote oil, and filling in with this coal tar composition and nailing our floor on to the sleepers. I have no particular data as to the life of these timbers, and do not know whether it is materially increased by the use of creosote oil. If I can get any information on this point, I will be glad to have it.

Emile G. Perrot.—One phase of this subject has not been touched upon; that is, the making of wood fire-proof by the injection of chemicals. As I understand it, the chemicals used for fireproofing purposes are entirely different from the chemicals used as a preservative. Is there any relation between these two methods?

Professor Alleman made a remark in reference to iron ties as compared with wooden ties, but he did not bring in the subject of reinforced concrete ties. The question of durability of wood in structural engineering has always been uppermost in the minds of engineers, and we have always been looking around for something to supplant it. I believe the reinforced concrete ties have been tried by railroads, and I would like to know whether they have been successful.

P. A. Maignen.—Professor Alleman says "I believe that the proper salt for timber preservation is one that is slightly soluble—just so soluble that it will form toxic doses for organisms of decay, thus checking their development. A cheap and efficient compound is still to be found." The salt or salts employed for this purpose should, in my opinion, be entirely soluble, in order that they might penetrate and reach every pore of the wood. They should not be such as to be liable to precipitation or coagulation on the surface or within a short distance of the surface, as is the case with bichlorid of mercury.

One of the best means of preventing the growth of microörganism in wood is to free it of moisture, particularly of that kind of moisture which is known as sap, and which contains not only water but also albumin, gums, and proteids; these substances are the food on which microörganisms thrive, particularly when the tree is deprived of its vegetable life.

It is well known that wood dried naturally keeps better than wood dried artificially, and that the better it is dried the better its staying power. The same phenomenon obtains with meats, fruits, and vegetables. Reduce the moisture to a given degree and the organisms of decay will not proliferate.

A writer in a recent number of the Railway and Engineering Review (March 2, 1907) under the heading "Treating Wood" says: "First sterilize the germs of decay by heat, either that of steam or that of hot air in drying ovens. . . . Some hold that the germs of decay exist in the sap of the wood before it is cut down and some believe that these germs penetrate into the wood after it is treated." I believe that the "germs" of decay do not exist in the healthy sap any more than they are to be found in the healthy living blood or in the milk that is still in the udder. When a wound is inflicted to a tree, it opens up a door for the entrance of the organisms just as wounds on animal flesh or on fruit. A cut piece of timber is covered with wounds all over and it would be a hopeless case to try to kill the germs

that come on them from the atmosphere or from the earth. The only sensible thing to do is to ignore the germs and take away their food. This is done naturally in the case of peat, and that is why peat is so slow in decaying.

We have seen in the paper of Professor Alleman, how very much injury is done to the timber by steaming. This process seems to be about as wise as to starve a man nearly to death in order that doctors may put in him some drugs to bring him to a healthy condition again. The best results are to be expected from a hygienic treatment and not from a medical treatment.

Carl Hering.—There is a simple and ingenious method which I understand is in successful use in Norway and Sweden, in which the forces of nature are called upon to do the work. It is based on the fact that what causes decay in wood is the sap which remains in it when the tree is felled. To get this sap out the lumbermen chop off the bark of the living tree for a few inches, completely encircling the tree near the roots. The tree then goes on living for a time, but as the sap cannot then go up through the bark, the tree lives on the sap remaining in the wood until it finally dies, having exhausted from the wood all the starch or other perishable material that causes decay. In this way I understand they prepare telegraph poles with very good effect.

J. S. Francis.—I feel more or less of an interloper here tonight, and do not know that I ought to say anything. However, we have had a good deal of experience with creosoted lumber under ground. The creosoted timber just taken out of Market Street, where it has been for the past 15 or 17 years is practically as good as new, and we are using it over again. The question of poles, however, is a serious one. A pole usually has to stand a different sort of wear from a railroad tie; all the decay comes in a length of six or seven feet from the butt end. There is not usually time between the cutting of a pole and the using of it to permit it to get properly seasoned, and it will not take anything except an injection treatment. Of course the creosoting includes artificial seasoning, but any preservative is practically worthless as applied to unseasoned timber. I am sorry I cannot give you the necessary data on this side of the proposition, but we are just beginning to realize the seriousness of this question. The Forest Service at Washington, and, I understand, the Reading Railroad, are conducting experiments in the line of treating ties, poles, etc., in an open tank; a boiling treatment with something like the dead oil from coal tar, in view of getting a cheap treatment to be applied locally. The trouble in getting creosoted poles is that we have to ship them to the Creosote Yards at Norfolk and pay the freight back again. That of course makes them expensive. If we can get an open tank treatment by which we can treat a pole for the critical part at the ground line, which is more subject to decay that the top, so that the life of all parts of the pole is the same, and do it cheaply, we will get the answer.

J. Kay Little.—I would like to ask whether the Professor can explain the long life of the old wooden water pipes in this city, some of which are said to have been in the ground for over a hundred years.

Edgar Marburg.—As a matter of interest in connection with the subject before us, I may say that experiments are reported to be in progress now looking to the replacement of wooden poles for long distance telephone lines by poles made of reinforced concrete.

The speaker has called attention to the very unsatisfactory experience had with

creosoted piles in connection with some government work at Norfolk. Since such work is usually executed under very rigid specifications and conditions of inspection, the question suggests itself whether it is practicable to determine with certainty in advance that the creosoting of piles has been done in such a way as to insure protection against the teredo, or whether even under the most favorable conditions there remains necessarily an element of uncertainty.

I should also like to ask the Speaker whether the creosoting of cross-ties is found to serve as a permanent protection against the ravages of the white ant.

John G. Brown.—I should like to ask why it is that the teredo seems to have a preference for oak and avoids the chestnut. We have found that with pine or oak, if you strip off the bark, the pile would go very quickly and be eaten up in as little time as ten months.

Gellert Alleman.—Creosote oil and "dead oil of coal tar" are synonymous terms. When crude coal tar is distilled we obtain light oil which contains benzol, toluol, etc.; then middle oil, which contains carbolic acid, naphthalene, etc.; then heavy oil, or creosote oil, or dead oil, which contains some of the tar acids, naphthalene and a little anthracene; then anthracene oil, and finally pitch. The first distillation does not give a sharp separation of the various compounds contained in the coal tar. Oils which cannot be profitably marketed are added to the "creosote well" and sold for creosoting. We, in this country, do not supply the same grade of oil as they do abroad, because abroad they have a market for hard pitch, which we do not have. In Italy hard pitch is used as a briquette binder. I suppose few briquettes are made here.

Creosote oils differ very widely on account of being produced from different tars, which have, in turn, been made from different coals which vary in chemical composition; or from coals which have the same chemical composition, but which have been differently treated. For instance, take the same coal which has been treated under two different conditions. They use the same coal both at Everett, Mass., and at Sidney, C. B. At the latter place they heat the coal up to a very high temperature in coking it, and at Everett they do not heat it so high, and at the two places they get entirely different coal tars. The creosote oils obtained by distilling these coal tars are entirely different.

Regarding the preservative compounds in creosote oils: the tar acids are powerful antiseptics; naphthalene may not be a powerful antiseptic, but it acts as a mechanical plug and aids in keeping the antiseptic materials in; then there is a portion of oil distilling between 245° and 270° C. which has marked antiseptic properties, and finally anthracene oil, which also is of an antiseptic nature.

Carbolineum is a composition originally made by heating zinc chlorid with anthracene oil. It is a good preservative agent. It is no better, however, than straight creosote. The railroads specify that their creosote oils shall contain high boiling materials. The railroad specifications have been published in various places.

As to the question of the scientific nature by which wood is preserved, I would answer that the intention is simply to preserve it, first against decay, and then against the teredo. In the case of the teredo we find that the teredo doesn't like certain grades of creosote oil. In the case of fungi, the antiseptic acts as a distinct poison against those organisms. Here is a piece of decayed wood which I picked up to-day. Here you see some mycelium; I do not know what the par-

ticular fungus is, but it is doing its work, as you see by the manner in which it is disintegrating this piece of wood. The action is different on different woods. These threads extend through the fiber of the wood into the cells excreting enzymes which convert the starch into chemical compounds which can be used by the fungus as food.

As to the efficiency of the superficial treatments of wood these methods are efficient to a certain extent, but to a relatively small extent. If the timbers were thoroughly treated they would last indefinitely. In the outside covering you refer to there is a decided protection, but I would say it is limited.

There is no relation, except in the processes, between fireproofing wood and preserving wood. You can fireproof wood by adding ordinary alum or ammonium sulphate, etc., but these may or may not be preservative agents. Creosoted wood will burn at a high temperature.

The only reinforced concrete ties with which I have had any experience were made under the direction of the late Professor J. B. Johnson at St. Louis. So far, they are failures. Professor Newberry, at Sandusky, made extensive experiments there, but I do not know whether he has ever published the results. From my conversation with him, however, I inferred that his experience was the same as my own. The principal hydraulic constituent in Portland cement is tricalcium silicate. This compound has the power of taking up water of crystallization and hardening. In so doing it forms well defined microscopic crystals. These crystals are subject to fracture under impact. Hammer blows will effect this result. The resultant of the revolution of a driving wheel is similar to a hammer blow and will accomplish the same result. This accounts for the failure of cement ties. Provided a sufficiently elastic cement tie could be produced the difficulty would be overcome.

Regarding the "vulcanizing process," the New York Elevated, I think, heated nearly all their ties to a temperature of from 470° to 600° F., under a pressure of 175 pounds. It was claimed that the wood was slightly decomposed and that antiseptic compounds were formed in it. As a matter of fact, the outside cell walls were broken down, and the outside badly injured. The heat did not penetrate to the interior and the latter remained intact. The wood so treated did not give satisfaction and the method was abandoned.

For some years I have been testing the relative resistance of timber destroying fungi when fed and at the same time poisoned by various chemicals. Various percentage solutions have been tried and the toxic dose for each determined. These tests developed many surprises. For instance, zinc chlorid is not a very powerful antiseptic as supposed. Alum is almost useless. Mercuric chlorid, even in extremely dilute solutions, is fatal. Iron salts have little toxic action. These fungi grow well on bread, potatoes, prunes, and invert sugar. They do not grow well in the ordinary culture medium. They feed on gums, resins, and starches.

As to the long life of the old wooden water pipes in Philadelphia I would state that the organisms of decay require oxygen, and in some cases nitrogen; they also require moisture and food. In your one hundred year old water pipes the water has been running so long that it has worked out all the food. The same is true of sunken logs, which, in fresh water, will often be brought to the surface in good condition after a submersion of many years.

It should be borne in mind that the teredo has nothing to do with decay. Wood

full of holes is not rotten wood, but has been perforated by the teredo. He has taken the wood out and shot it into the water. It is simply mechanical destruction.

Answering Professor Marburg's question, I would say that specifications for creosote can be drawn up to furnish you with an oil that will protect, without doubt, against the teredo, limnoria, and xylotry. The cause of failure in most cases is due to the use of poor material and to fraud; fraud in not injecting the amount of material called for. I was called upon some years ago by a foreign government to look into some timber that was shipped for use as piling. This timber was guaranteed to contain sixteen pounds of creosote to the cubic foot, and the largest amount of creosote found in any pile was seven pounds. In one specimen I found only three pounds. The timber treater ran in an emulsion of steam and creosote oil. The steam condensed inside the wood filling some of the wood cells and prevented a thorough penetration of the oil. There is absolutely no reasonable doubt regarding the efficiency of creosoting, provided the man who does the treating does his work well, and the material used is of a good grade.

If you will read the December, 1904, Proceedings of the Pacific Coast Railway Club, in which Mr. James McKeon discussed the creosoting proposition, you will conclude, from the examples cited by Mr. McKeon, that considerable damage has been done to creosoted piling on the Pacific Coast. The cause of failure was due either to the poor quality of the oil used or to an insufficient quantity of the same. The teredo and the limnoria are particularly active on the Pacific Coast. Twenty pounds (to the cubic foot of timber) of a high-grade creosote oil will furnish an efficient protection.

I have not had any personal experience with the white ant, but I have been told that it will not attack creosoted wood.

As I am not a conchologist, I cannot answer fully the question as to how the teredo works. It is said that the teredo rotates his head and hollows out his gallery with an action analogous to a file. The head is a calcareous silicious material, and there is no chemical solvent of wood exuded by the teredo. I say "it is said," because I have recently talked with Professor Dall, of the Smithsonian Institution, and I have gone into the matter at the Academy here, but, when you mention teredo, everybody seems so non-committal. I think the consensus of opinion is that the teredo does not make use of chemicals to hollow out his galleries, but simply cuts his way through as you would with a file, and exudes the powdered wood. I believe that the teredo works only in salt water. A new variety of teredo was found one hundred miles from the coast of Florida, in water which is not brackish. He does not usually work below the mud-line, to a greater distance than the length of his body.

Creosote is used in the south for fence-posts. Most bridge timbers in the southwest, where decay is more rapid than in this section, and where inferior woods are necessarily used, are creosoted. From the standpoint of safety and economy it is an absolute necessity in many sections of the country.

Regarding the advisability of creosoting the wooden ceilings which are put under bridges to protect the metals from the locomotive gases, I would say that it would pay to creosote it, and that it would last about twenty years. Assume that the lumber which you use in these ceilings cost $30 per thousand. It costs you an additional $30 per thousand for applying three coats of paint to each side. This

means $60 per thousand for the two items. You say the ceilings last seven years. Figuring at 4 per cent., this means that the annual charge against each thousand feet of lumber is $10.

Now assume that your lumber costs the same amount and that you paid $30 per thousand for creosoting it, instead of painting it. As a matter of fact you would not pay over $20 for creosoting it. But assume that your creosoting costs as much as your painting. Now you have an investment of $60, which must bear interest so as to renew itself at the end of twenty years. In this event, the annual charge against each thousand feet is only $4.41. In other words, if the creosoted ceiling really would last twenty years, you would have an annual saving of $5.59 for each thousand feet used. Assuming that your creosoted timber lasted but fifteen years, the annual charge would be $5.40, which would mean an annual saving of $4.60 for each thousand feet.

It is surprising that there are not creosoting plants right here in Philadelphia. There are two plants in Norfolk, one in Jersey City, and one in Perth Amboy.

I do not know why the teredo has a preference for oak and avoids the chestnut, but I can readily see that there are chemicals in the sap of the chestnut that might be objectionable to them. There would be a large amount of tannic acid in the oak bark. This may be objectionable to the young teredo.

ABSTRACT OF MINUTES OF THE CLUB.

BUSINESS MEETING, February 2, 1907.—President Quimby in the chair. Seventy-one members and visitors present.

The Tellers reported the election of Joseph G. Shryock to active membership and Willis L. Essen to junior membership.

Mr. F. E. Wynne read a paper on "Application of Single-phase Motors to the Operation of Electric Railways."

REGULAR MEETING, February 16, 1907.—President Quimby in the chair. Ninety-seven members and visitors present.

Mr. H. W. DuBois read a paper on "Hydraulic Gold Mining in British North America."

BUSINESS MEETING, March 2, 1907.—President Quimby in the chair. Seventy-six members and visitors present.

The annual address delivered by President McBride on January 19, 1907, was then discussed.

The Tellers reported the election of C. F. Cludius and W. H. Fulweiler to active membership.

REGULAR MEETING, March 16, 1907.—President Quimby in the chair. Sixty-nine members and visitors present.

Professor Alleman presented a paper on "Modern Methods Employed for the Preservation of Timber against Decay and Teredo. Statistics of Consumption, Technology, Cost, and Conditions Justifying Treatment."

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

ORGANIZATION MEETING, January 28, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Dodge, Easby, Ledoux, Loomis, and Perrot, the Secretary, and the Treasurer.

The President announced the appointment of the following committees: *Finance,* W. P. Dallett, Wm. Easby, Jr., and J. W. Ledoux; *Membership,* Wm. Easby, Jr., F. E. Dodge, and W. P. Dallett; *Publication,* Emile G. Perrot, Wm. Easby, Jr., and Francis Head; *Library,* Washington Devereux, J. W. Ledoux, and John T. Loomis; *Information,* Francis Head, Washington Devereux, and Emile G. Perrot; *House,* John T. Loomis, Washington Devereux, and F. E. Dodge.

The Tellers of Election were appointed as follows: W. E. Bradley, I. W. Hubbard, H. P. Cochrane, Alan Corson, W. W. Nichols, and H. G. Perring.

The following were appointed Auditors: H. W. Spangler, Richard L. Humphrey, and W. B. Riegner.

The following appropriations were made for the coming year: House, $2900; Library, $250; Publication, $1000; Information, $150; Office, $750.

It was moved and carried that the agreement to abide and be governed by the By-Laws and Constitution as signed by an applicant in his application for membership is sufficient compliance with the provisions of Sec. 8, Art. V, of the By-Laws, and that the practice of sending out supplementary agreements be discontinued.

The resignation of R. W. Tull was accepted as of January 1st.

The Secretary read a letter from Mr. O. G. Smith, stating that he would withdraw his resignation and become a non-resident member.

It was moved and carried that the Publication Committee be authorized to print papers in advance whenever practicable.

It was moved and carried that the Advertising Committee be authorized to include in the next Directory a list of books in the Club Library, and also that reprints of these lists would be made for other circulation.

Regular Meeting, February 16, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Head, Easby, Ledoux, and Perrot, the Secretary, and the Treasurer.

The report of the Treasurer for the month of Jauaury was read and accepted as follows:

Balance December 31, 1906,	$3923.67
January Receipts,	2400.00
	$6323.67
January Disbursements,	286.30
Balance January 31, 1907,	$6037.37

It was moved and carried that the salary of the Treasurer be raised to $180 per year, and that that of the Secretary should remain as at present.

It was moved and carried that the Club should exchange Club House and Library Privileges with the Technology Club of Syracuse.

Complaints having been received from members of the non-receipt of copies of the Proceedings, it was moved and carried that when such complaints are made promptly, additional copies will be sent, but that when such requests are made a year or more after the date of issue, members shall be required to pay for extra copies.

Regular Meeting, March 16, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Dodge, Easby, Head, Ledoux, Loomis, and Perrot, the Secretary, and the Treasurer.

The report of the Treasurer for the month of February was read and accepted as follows:

Balance January 31, 1907,	$6037.37
February Receipts,	730.00
	$6767.37
February Disbursements,	483.95
Balance February 28, 1907,	$6283.42

It was moved and carried that the House Committee be authorized to obtain a new lantern, at a net cost not to exceed $160.00.

The subject of separate telephones for the office and reading room and also of installing a Keystone telephone was held over for future consideration.

ADDITIONS TO THE GENERAL LIBRARY.

FROM ROBT. G. DIECK.

Annual Report of the Municipal Board of the City of Manila.

FROM JOS. T. RICHARDS.

Record of Transportation Lines of Penna. R. R. for the Year Ending Dec. 31, 1906.

FROM AMERICAN WATER WORKS ASSOCIATION.

Proceedings of the 26th Annual Convention of American Water Works Association.

FROM WATER SUPPLY COMMISSION OF PENNA.

Report of Water Supply Commission of Penna., 1905–1906.

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Catalogue, Glasgow Iron Co.

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27th and 28th Annual Report of the City Engineer of Lawrence, Mass., 1904 and 1905.

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FROM SMITHSONIAN INSTITUTE.

Nova Scotian Institute of Science, vol. xi, No. 2.

Asulkan Glacier, Showing Névé, Ice Fall, Tongue, and Moraines. (Page 281.)

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MODERN GLACIERS: THEIR MOVEMENTS AND THE METHODS OF OBSERVING THEM.

WM. S. VAUX.

Read May 18, 1907.

THE study of glaciers, including their present changes and the part they have taken in fashioning the earth's surface, may be broadly divided under two great heads. One deals almost exclusively with the science of geology, and embraces a consideration of changes in the earth brought about by the activity of glaciers which may have ceased to exist ages ago. The other treats of glaciers as they are found today, the properties of ice, the laws which govern formation, flow, and dissipation, and deals with physics and physical laws.

The second of these great branches will largely occupy attention in the present paper in explaining what a glacier is, illustrating its principal characteristics, and giving a brief summary of the history of glacier investigation. Lastly, the plan of observation on some of the glaciers on our own continent will be explained by which these movements and changes have been recorded, and some of the laws of glacier action again applied to new examples.

The popular conception of ice as a hard, unyielding substance is in fact totally wrong. Ice is really viscid, and will slowly yield to pressure if not intense enough to rupture it, but will crack and split if the pres-

sure is suddenly applied or its direction changed. This is the case in compression, but the yielding to tension is very small, and is followed by a more or less complete rupture. Indeed, a mass of ice may be compared with tar, which, though solid and firm, is brittle under tension, but plastic under compression, and will change its form until the pressure is relieved. This property of ice may be considered the fundamental one which permits masses at high altitudes to assume the flow of a river and drain away into the warmer valleys below.

In general, it may be said that a glacier is a mass or stream of ice

PLATE 1.—AVALANCHE, VICTORIA GLACIER. THE ICE IS HERE FALLING 2500 FEET AND FORMING A SECONDARY GLACIER BELOW.

formed in regions of perennial frost from compacted snow, which moves slowly downward in a manner analogous to a river over slopes and through valleys until it melts away, owing to higher temperature at the lower levels, breaks off in the form of icebergs on the border of the sea, or avalanches over cliffs to the valley below.

It is only under favorable conditions that glaciers are formed—an average temperature below 32° F., a high yearly precipitation, and a climate which allows an accumulation of snow in excess of the amount

melted, evaporated, or blown away. Outside the Arctic regions these conditions are found only at high elevations, and it is for this reason that with high mountain ranges and rugged peaks one mostly associates snow-field, glacier, and moraine.

Glaciers may be divided according to three principal types: *Alpine,* where the snow is at a considerable elevation on a mountain side, and the stream flows through a valley to the open slopes below. This type is the most widely known, and was first studied in the Swiss Alps, where the name was applied. *Piedmont,* where several alpine glaciers unite and spread out over the adjacent valley or plain; and *Continental,* where vast areas, or even entire continents, are covered. Examples of the third type are at present to be found only in the Arctic and Antarctic regions, but in past ages they were more numerous and extended; the great ice caps over North America being excellent examples. It is with the alpine and piedmont types that we shall deal in the present discussion, as apart from being more readily accessible, they exhibit the glacier characteristics which are to be illustrated.

A glacier being a river of ice, its source is at a high elevation where snow falls throughout the year, and for a large portion of the time the temperature is below freezing. There being no melting, the snow becomes deeper and deeper and an indefinite accumulation would in time take place, were it not that pressure from the increasing load above and many changes of temperature close to the freezing-point begin the direct transformation of snow to ice without melting of the whole mass. Then begins the slow and constant motion or flow to the lower levels. More snow falls on the surface above, forming a vast field resting on the mountain-side, while below is a mass of solid ice—the birth of the glacier. This snow-covered portion is known as the *accumulator* or *névé.* Following the course of the ice-stream, a point is reached where owing to increased temperature and lower elevation the accumulations of snow on the surface melt before a large amount has collected, uncovering the stream of solid ice, which becomes visible, and here the dry glacier begins. Below the snow line to the *tongue* or *snout* where the glacier melts away there is surface melting, and the phenomena of ice action may be studied in full view. This lower portion is known as the *dry glacier* or *dissipator.*

Glaciers may be simple or compound as they drain one névé into one valley, or are made up of a number of individual streams each filling a separate valley with a common snow-field. Conversely, several névés may be drained by glaciers in valleys which finally join and form one ice-stream.

The crystalline structure of the ice composing a glacier is very different from that frozen in the ordinary way. The snow falling at high altitudes is usually of a hard spherical form, similar to hail, which is compacted together by pressure and slight temperature changes till it assumes a banded or stratified form of solid ice with a peculiar grain and structure which instantly distinguish it from lake or river ice. Near the tongue the grains become larger, but are crushed together and deformed as in a mass of marble.

The snow when it first falls exhibits no bands or stratification. Alternate melting and freezing and the deposit of dirt on the surface blown from cliffs form stratified layers of clean, dirty opaque, and clear ice, the bands of which dip at an ever-increasing angle as it descends. Near the tongue these bands become obliterated, the ice being of an even clear texture, interspersed with lines of dirt or faults formed by cracks in the ice which have afterward closed.

Plate 2.—Crevasses, Illecillewaet Glacier.

The beautiful coloring of pure glacier ice is universally noted, and also the peculiar bandings of the clearer sections, which do not appear in the névé, but become marked in the lower regions, and disappear

before the tongue is reached. These are known as *blue bands*, and their formation has long been under investigation. They are not equally marked at corresponding points in different glaciers and their position and direction do not appear to follow known laws. The suggestion of Prof. Louis Agassiz, that they are formed as a result of horizontal pressure in the ice similar to cleavage in slate, has been accepted for many years. Recently theories have been advanced to prove that they are analogous to strata in the ice, or that they are the result of a modification in the névé stratification.

Above the névé line, owing to absence of melting, the tendency is for

PLATE 3.—SÉRACS, ILLECILLEWAET GLACIER.

the ice to become thicker and to bury rock or other substances which may rest on the surface. Below this line the conditions are reversed; melting takes place which constantly removes the upper layers of ice, and the flowing motion below gradually brings these buried substances to the surface. It is for this reason that the upper slopes of glaciers are generally white and clean, while below they are often buried deep in débris.

Two of the most striking characteristics of glaciers are crevasses

and moraines. Owing to the impossibility of ice yielding to tension except in a very limited degree, some provision must be made for uneven flow.

As the glacier flows over the rock-bed or reaches a space of increased incline, tension is exerted in the ice which causes a rupture. The cracks, but a hairbreadth wide at first, are enlarged by melting and changes of slope, till they may be hundreds of feet in length and many feet deep and broad. These are known as *crevasses* (Plate 2), and they are formed in the partially consolidated snow, in the ice beneath the snow, or in the dry glacier itself. Early in the season the crevasses are filled with snow, which later melts, and *snow-bridges* are formed. These are at first strong and solid, but soon melt away from below and form treacherous pitfalls for the explorer. Crevasses may run in any direction, and often form a maze on the ice surface through which it is hard to thread a way, and where the greatest caution is necessary. When these cracks occur at angles to each other pannicles of ice are formed. Melting takes place on the four sides thus exposed to the air, and *séracs* are formed, named from a fancied resemblance to clotted cream. These often assume the most fantastic shapes after the erosion of wind and water has worn them away. (Plate 3.)

Passing over an uneven bed the body of the glacier is first bent in one direction and then in the other. When the slope increases great openings are formed across the glacier which are known as *transverse crevasses,* as they usually occur nearly at right angles to the direction of flow. The ice at this point may form in great steps with crevasses between them. This is known as the *ice fall.*

When the slope is almost constant no crevasses are formed from this cause, but the more rapid flow at the center than at the sides causes a stretching at this point and *marginal crevasses* result.

Again, crevasses may be found where a glacier after passing through a narrow defile spreads out into a wider space which allows it to expand laterally with a corresponding decrease in motion. The pressure of the ice behind produces a tension in the ice which forms *longitudinal crevasses.*

Between the main stream of the glacier and the bordering cliffs deep and broad openings similar to crevasses are almost always found. These are known as *bergschrunds* or *mountain crevasses,* and they may occur close to the rocky cliffs or several rods distant, a portion of the névé being closely attached to the rock wall.

At times narrow cracks or even large crevasses are filled with water

which freezes and forms a solid mass. They are very noticeable on the dry glacier and are known as *dykes.* The ice so frozen is often composed of long crystals the axis of which is at right angles to the plane of the crack, or may be of the glacier form after having been subjected to pressure.

The walls of crevasses where there has not been much melting are often of the most exquisite turquoise blue, which deepens to black in the farthest depths. Frequently icicles are formed which hang row on row with silver-white or blue bands and wreaths. When the sunlight enters one of these chasms, every point and drop reflects the light, while deep pools of water make it seem like an enchanted fairyland. It has been said that only the unfathomable sea rivals this exquisite coloring and setting.

While not strictly connected with our subject, a peculiar phenomenon often noticed on the higher névés is *red snow.* This is, in fact, a vegetable growth in the snow itself, which at times covers many acres of surface. It is often covered with a layer of fresh fallen snow and its presence is not suspected until foot-marks or the scraping of the ice-axe uncover it. There are said to be several species, each with its own locality and limits.

The transporting power of glaciers, at one time seriously doubted, is now universally accepted. The immense amount of rock deposited in valleys and plains bears witness to the part played in the past, while the masses carried, polished, and ground at the present time show how the work of ages has been accomplished. All glacier-transported material is known under the head of *moraine.* There are two main divisions, indicating whether the material is fixed or is changing with the motion of the ice, and these are again classified according to their position relative to the glacier. If at the tongue, they are known as *terminal;* at the side, *lateral* or *marginal;* beneath, *sub-glacial* or *ground;* while two lateral moraines coming together when ice-streams join and flow as one are known as *medial* moraines. The amount of transported material varies greatly, some glaciers being almost free, and others so covered that they resemble plowed fields. The proximity of disintegrating cliffs or rocky walls from which masses break off produces moraines, while an absence of such cliffs forms a clean glacier, the tongue of which may not be buried. Moraines are often of great height and length, but generally of a triangular cross-section ending in a ridge with the masses of rock just at the angle of repose. Often they appear to be solid, but really rest on a stagnant core of ice which gradually

wastes away, and the slow shrinking starts masses of rock and dust which avalanche down the sides. Large isolated rocks or *bowlders* are usually found resting on the surface of the ice, firmly fixed on the crest of moraines or resting entirely apart from the other débris in the valley bottom below. These are known as *erratics,* and they often show the results of enormous pressure by their polished and grooved surfaces. At times the rock in place is scratched and polished, or worn off in mounds which fancifully resemble the backs of sheep, and are accordingly known as *roches moutainé.*

Moraine and crevasse make possible many minor glacier phenomena.

Plate 4.—Glacier Table, Victoria Glacier.

A bed of moraine over a foot thick acts as a blanket and protects the ice below from the sun's rays. Thus many moraines are really of ice with a coating of rock. A large rock protecting the ice below while the surrounding surface is melted away rises on a pier until it may reach a height of several feet. Always tipping to the south, the rock finally falls, owing to the melting away of the pillar below, and the process is repeated. These are known as *glacier tables.* (Plate 4.) When the rock is small the reverse is the case, and it sinks into a hole filled with

water melted by the heat absorbed. A mass of sand collected at the foot of a water-fall in the ice gradually comes to the surface and a *sand cone* is formed, of a thin coating of sand and a core of ice. (Plate 5.)

The ice meltings find a way to the depths of the glacier through crevasses, but at more level portions, where there are no openings, small streams collect which flow on the surface until a crevasse is reached. These streams may assume considerable proportions; canyons are formed with potholes and caverns through which water rushes with great force owing to the smooth sides. At a crevasse the water leaps down in a

Plate 5.—Sand Cone, Victoria Glacier.

moulin, or perhaps a hole carries it to the depths below. (Plate 6.) The water melted from the glacier collects in streams below the ice and flows on the ground moraine till it issues at or near the tongue. Great caverns are melted out as a result of the water or air currents, and at the point where the stream issues a beautiful *ice arch* may be formed. (Plate 7.) In the spring these arches are often of great size, but later in the season the ceilings fall in.

Glacier water may be readily distinguished from that melted from

snow by its gray, muddy character. This is caused by the suspension of a large amount of fine mud which has been ground from the rocks and cliffs. In the course of the stream this mud is deposited in flat places, and gradually fills up the lakes which often lie below glaciers. Further down the streams become clear and lose this characteristic owing to the filtering out of suspended material, but a small amount of mud always remains, and its presence is said to cause the vivid tints of the lakes, which when fed by glaciers often rival in coloring the ice itself.

The flowing motion of glaciers already referred to involves a most

PLATE 6.—MOULIN, ILLECILLEWAET GLACIER.

difficult problem in ice physics which is not yet thoroughly solved. No fewer than nine theories have been advanced to explain the phenomena observed. It is not within the province of this paper to attempt more than a brief description of phenomena, the obscure problems of the causes which produce the effects being left for those who desire to delve into them. The observed facts, however, show that the motion of a glacier resembles closely the flow of a river, except that it is much slower and only observable by the aid of instruments of precision.

As in a river, all portions do not move with the same rapidity. The surface moves faster than the bed, the center than the sides, and where a bend in direction is met, the concave side lags till the convex assumes its proper place. Indeed, it may be said that no two parts of a glacier travel with the same rapidity, for at a broad, open space the rate is slow, while a narrow, deep gorge accelerates the motion till the ice is broken into rugged masses, owing to the enormous pressure exerted. Again, the surface melting below the névé line tends to bring the lower portions to the surface, and in the dissipator there is a gradual motion

Plate 7.—Ice Arch, Yoho Glacier.

from the center to the sides. In the upper sections of a glacier the flow is least and increases to the névé line, where theoretically it is a maximum, and then decreases to the tongue. Where moraines and embedded rocks are not present the rate of flow is greater than where the glacier is heavily bedded in moraine or filled with rock.

These motions are constantly at work, but they do not act with the same speed at all times. Higher temperature may mean accelerated speed, and the summer flow has been proved in certain cases to be more rapid than the winter, and the day motion than the night, though the

causes of these changes are not as yet fully understood. Over a series of years the rate of these motions is found to vary, increasing for a time and then decreasing, passing through many changes in the course of a century.

Varying climate, precipitation, and rate of flow are the principal causes of glacier variation, which is now being investigated with great care. It is everywhere evident that in former times glaciers were of much greater extent than at present, and that there has been a decrease and shrinkage for many years. Valleys below glaciers, now covered with trees hundreds of years old, were in former times the bed of moving ice which bore down and deposited erratic and moraine. Lakes plowed out by immense force show where the ice masses once crushed together and then retreated and melted away. These changes depend upon the rate of flow of the ice, the amount supplied from the névé region, and the quantity melted away at the tongue. If more ice is supplied than is melted, the glacier advances; while if the melting exceeds the supply, the glacier retreats. Temperature, precipitation, and sunshine modify the result, so that many factors are at work to determine whether a glacier advance or retreat. These changes are independent of the daily and yearly variations, though they appear to be the result of similar forces acting over longer periods of time.

Careful observation extending over years has shown that after a time of retreat the ice begins to thicken in the névé region, the rate of flow quickens, and a great wave of ice flows to the tongue, which advances over the space formerly left bare. The glaciers in one locality do not all change at the same time, but some may advance while others retreat. It is, however, believed that the same cause in the névé is applied to all, but owing to size, length, normal flow, and other conditions the effect does not become apparent at the same time. Advances in many glaciers have been noted at periods of about thirty-five years, and this interval is known as "Brückner's period," though it can as yet hardly be considered as a fixed rule of glacier change except from theoretical considerations.

Prior to 1811 no general records of the variation of glaciers are preserved. In 1812 there was a general advance of all the glaciers of Switzerland, which reached a maximum in 1825. This is the greatest advance ever observed. A period of decrease then set in, not marked or universal, which was followed by a less decisive increase, which reached a maximum about 1850. Then followed a marked period of

decrease, and in 1870 all the glaciers were positively retreating. From 1875 a new phase set in, certain glaciers began to advance and others to retreat. This condition continued till 1894, when decrease became almost universal, and has continued more or less positive in character till the present time.

An illustration of the apathy of thinking men in the middle ages is shown by their lack of interest in natural phenomena. Roman engineers built roads through Switzerland, traveled them for centuries, and bridged and crossed glacier streams and even glaciers themselves with only the most remote references to their existence. The history of glacier investigation extends back barely more than two hundred years, for while Münster in 1544 and Schenckzer in 1707 advanced theories as to the structure and movements of glaciers, their ideas were crude and founded on wrong conceptions of actual conditions. DeSaussure in 1803 published in his "Voyages dans les Alpes" the first serious description of glaciers, based upon his own observations and deductions. At this time motion and variation were imperfectly understood, while until many years after it was thought that glaciers existed only within the confines of the Swiss Alps.

Charpentier in 1841 published his studies on the former great extension of the Rhone glacier from its valleys into the plains beyond, and this work drew to the attention of scientific men that problems of universal interest in glacier action remained to be solved. Hugi had lived in a hut on the ice in order to study the marvelous forces which were at work, an account of which he duly published. About this time Prof. Louis Agassiz, who had been occupied with zoölogy, turned his attention to present glacier action as a means of determining the past history of the earth. He saw that careful observation of present conditions would develop definite general laws which would apply for all time, and he set about to find the real nature of the movement of the ice-stream which had previously been assumed by observation of masses moving along on the surface. To him must be accredited the first scientific work in observing the movement of glaciers by means of stakes driven in the ice. Surface melting was unintentionally proved by all his stakes melting out of the ice and falling, but he persevered, living in a hut on the glacier, where he received many scientific men as his guests. His "Système Glaciaire," published in Paris in 1847, describes in detail the work, and is a classic in the literature of glacier investigation. As a guest of Agassiz, a physicist and surveyor, Prof. J. D. Forbes, first made the acquaintance of existing glaciers. He saw

that with instruments of precision the work which Agassiz had laid out could be performed in days instead of years, and on the Mer de Glace he placed a row of stakes, and a month later proved the motion of the ice, and that it is greater at the center than at the sides, resembling the flow of a river. With the subsequent bitter controversy as to priority of discovery we have nothing to do, but the laws laid down and the phenomena recorded at this period stimulated an interest in glacier study which has continued to the present day.

About this time Rendu, who had long been a student of glacier action, published the results of his investigations in "Theorie des Glaciers de la Savoie," in which he developed laws entirely independent of outside sources. The reason for motion and the real functions of moraines formed at this time the active problems for discussion, and many theories were advanced and argued, attributing glacier phenomena to different causes. Tyndall and Croll each developed theories of motion which attempted to reconcile observed facts with known physical laws, but all pointed to the importance of a systematic study of the subject with physical and mathematical considerations always in mind. This implied also a careful, painstaking observation of changes as they took place and a record compiled of all the data obtained. Prof. F. A. Forel, of Lausanne, realizing the value of such investigations, published in 1881 a memoir in which he laid down the fundamental laws of glacier variation and appealed to those interested in the subject to assist him in completing the records. In August of 1894, under the leadership of the late Captain Marshall Hall, the International Congress of Geology appointed a committee to systematically collect data and record facts relating to glaciers and their changes. This is known as the Commission International des Glaciers, and for a decade has collected data from all parts of the world and reduced it to a form for comparison. Brückner, Richter, Finsterwalder, Forel, Reid, Hess, Russell, and many others have contributed to the general store of knowledge, by observation on glaciers themselves, deducing laws from the information received, or developing the mathematical considerations which are intimately associated. The systematic observation of over one hundred glaciers, situated principally in Switzerland, but distributed generally over the globe, will in time provide the data from which correct ideas of glacier phenomena may be deduced.

It must be borne in mind that the forces studied have acted for untold ages, and that the contributions of one observer or even one generation of observers taken singly will form but a slender basis upon

which to weave ultimate results. Only by an intimate knowledge of the physics of ice, the changes in climate, and the results which these changes have upon existing examples will it be possible to correctly deduce the laws which have taken such an important part in preparing the surface of the earth for the habitation of man.

The foregoing outline of the characteristics of glaciers and the way in which they have been studied may serve as a prelude to a brief description of the conditions which form great ice-streams in Alberta and British Columbia, upon several of which measurements have been made. While these glaciers do not compare in size with those of Greenland, Iceland, and Alaska, they may yet be taken as average examples of the alpine type.

Excluding the territory which lies to the north of the Arctic circle, all the principal glaciers of North America lie within the great ranges of the Rocky Mountain cordillera. These ranges, stretching from south to north along the Pacific coast, are well located for the formation of glacier streams on their western slopes. Mountains such as Lyell, Hood, and Rainier within the United States bear glaciers near their summits, but it is only to the north of the boundary with Canada that the conditions become truly alpine and glaciers exhibiting all the phenomena are to be found. The course of the ocean currents in the Pacific and the position of the mountain ranges near the coast are both favorable to the formation of glaciers of great extent. The Japan current, flowing north some hundreds of miles from the coast of California, gradually approaches the continent till the western shore of British Columbia and Alaska are bathed by its warm waters. Warm winds blowing eastward gather up the moisture and carry it inland, where the Rocky Mountain cordillera is crossed, here composed of four ranges—the Cascade, Gold, Selkirk, and Rocky Mountain. Each succeeding range from west to east is higher, and these moist, low-lying clouds lose their moisture on the western slopes, thus causing a heavy precipitation. This falls mostly in the form of snow, and supplies the névés, which in turn feed the innumerable glaciers of the district. Clouds in higher strata pass above the highest ranges, and later their moisture is deposited on the great wheat plains of Alberta and Manitoba.

Until the completion of the Canadian Pacific Railway in 1885 the glaciers of this region were practically unknown. Mackenzie in 1789 and Capt. John Palliser in his expeditions of 1857–59, with their many

branch excursions under the leadership of Sir James Hector, naturally kept mostly to the valley levels far below the tongues of the largest glaciers, as their object was to find an easy direct route for a wagon-road between the Pacific and the plains to the east. But in order to meet the requirements of railway engineering mountain passes had to be crossed, and thus glaciers which rival those of any other section in interest were brought within easy reach.

The most accessible of these lie close to the main line of the Canadian Pacific railway at Glacier House, a station about 500 miles east of the

PLATE 8.—ROCK "E," ILLECILLEWAET GLACIER, PARTLY BEDDED IN ICE, JULY 16, 1887. (COMPARE PLATE 9.)

western terminus at Vancouver. Several glaciers are within a short distance of this point, but the one most readily reached is the Illecillewaet, the tongue of which is but one and one-half miles from the hotel. Prior to 1883, when the pass bearing his name was discovered by Captain John Rogers, the foot of man had probably never trod its valleys, as the course was many miles from the usual route, following down the Columbia River. During railway construction the glacier was doubtless often visited by those stationed on the work, but no records were made until July 17, 1887, when our party, passing through, roughly mapped

the tongue and made a photographic record of the conditions as they existed. (Plate 8.) At that time the ice completely covered the ground moraine as far as the ridge of bowlders, among which alder bushes were growing. The slope of the ice at the tongue was very steep, and the proximity of alder bushes of considerable age close to the border proved that the ice had been in a maximum position for many years. The next year (1888) the Rev. Wm. S. Green spent some time in the district and noted that the glacier had receded somewhat from the year before. He daubed tar on bowlders bordering the ice which are marked "T. T. T."

Plate 9.—Rock "E," Illecillewaet Glacier, August, 1899, Showing Shrinkage of Ice. (Compare Plate 8.)

on the map, and made a rough determination of the flow at a point above the tongue by means of stakes driven into holes. After twelve days a stake near the center moved twenty feet, and at the side seven feet. These daily movements are greater than those recently recorded at similar locations when the glacier is evidently retreating.

In 1894, when we again visited this glacier, it was evident that retreat had taken place and changes occurred which we were then at a loss to account for. Our interest was again excited when in 1897 we found

still greater changes, which resulted in yearly visits since, including the summer of 1906, and the preservation of careful records of what is taking place. (Compare Plates 8 and 9.)

These may be divided under several heads: "Recession and Advance"; "Rate of Flow"; "Topographical Map"; and "Photographic Record."

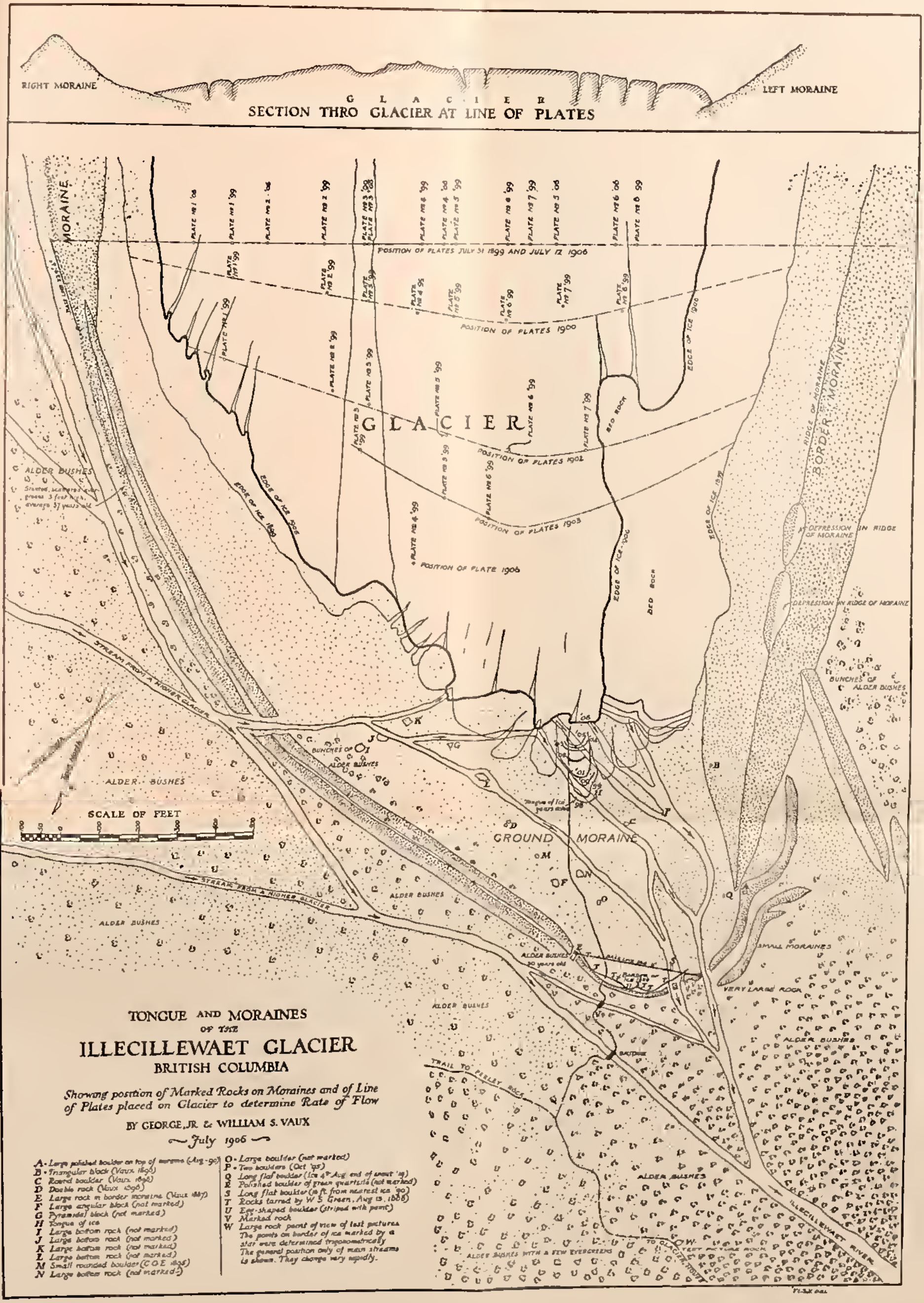
In glaciers similar to the Illecillewaet the recession or advance of the tongue between two dates is a simple matter to determine. Being almost free from morainal material, the tongue extends on an almost flat ground moraine and melts away to a point. From year to year this point moves to the right or to the left, but its position being readily found, the distance to range lines between marked rocks is easily obtained. The selection of these range rocks is a matter of great importance, for while the general tendency of the glacier may be to retreat, the winter advance may be sufficient to engulf the bowlders and push them down to obliterate the marks entirely. The rock marked "C" on the map has been used as a base from which to measure the changes in this glacier since 1898, but in order that no changes might take place in it a range line between "B" and "D" just touched the tongue the same year, and a careful comparison of angles at once makes any alteration in the position of these bowlders apparent. Since 1898, and almost certainly since 1887, the glacier has receded each year, but records are available only since 1898, as shown in the following table:

ILLECILLEWAET GLACIER.—RECESSION OF TONGUE OF ICE FROM ROCK "C."

Date of Observation.	Distance Tongue of Ice to Rock "C."	Recession of Ice Since Previous Year.
Aug. 17, 1898	60 feet.	
July 29, 1899	76 "	16 feet.
Aug. 6, 1900	140 "	64 "
Aug. 5, 1901	155 "	15 "
Aug. 26, 1902	203 "	48 "
Aug. 25, 1903	235 "	32 "
Aug. 14, 1904	240½ "	5½ "
July 25, 1905	243 "	2½ "
July 24, 1906	327 "	84 "

An interesting point is that the recession from 1890 to 1898, when the yearly record was begun, averaged 56 feet a year, while from 1898 to 1906 it averaged but 33.3 feet, or about three-fifths.

To determine the rate of flow of the ice on the surface at a line above the tongue a much greater length of time and more care are required. Many observers in Switzerland, and Rev. Wm. S. Green on this glacier,


RIGHT MORAINE
GLACIER
LEFT MORAINE
SECTION THRO GLACIER AT LINE OF PLATES
MORAINE
POSITION OF PLATES JULY 31 1899 AND JULY 12 1906
POSITION OF PLATES 1900
GLACIER
POSITION OF PLATES 1902
POSITION OF PLATES 1903
POSITION OF PLATE 1906
EDGE OF ICE 1906
EDGE OF ICE 1899
BED ROCK
DEPRESSION IN RIDGE OF MORAINE
RIDGE OF MORAINE
BORDER MORAINE
ALDER BUSHES
STREAM FROM A HIGHER GLACIER
SCALE OF FEET
GROUND MORAINE
SMALL MORAINES
VERY LARGE ROCK
TRAIL TO PERLEY ROCK
ILLECILLEWAET RIVER
ALDER BUSHES WITH A FEW EVERGREENS
TONGUE AND MORAINES
OF THE
ILLECILLEWAET GLACIER
BRITISH COLUMBIA
Showing position of Marked Rocks on Moraines and of Line of Plates placed on Glacier to determine Rate of Flow
BY GEORGE, JR. & WILLIAM S. VAUX
July 1906
A· Large polished boulder on top of moraine (Aug-90)
B· Triangular block (Vaux 1890)
C Round boulder (Vaux 1898)
D Double rock (Vaux 1898)
E Large rock in border moraine (Vaux 1887)
F Large angular block (not marked)
G Pyramidal block (not marked)
H Tongue of ice
I Large bottom rock (not marked)
J Large bottom rock (not marked)
K Large bottom rock (not marked)
L Large bottom rock (not marked)
M Small rounded boulder (C.O.E. 1898)
N Large bottom rock (not marked)
O· Large boulder (not marked)
P· Two boulders (Oct '95)
Q Long flat boulder (Ice 4th Aug end of snout '99)
R Polished boulder of green quartzite (not marked)
S Long flat boulder (ft. from nearest ice '90)
T Rocks tarred by W. S. Green, Aug 13, 1888
U Egg-shaped boulder (striped with paint)
V Marked rock
W Large rock point of view of last pictures
The points on border of ice marked by a star were determined trigonometrically
The general position only of main streams is shown. They change very rapidly.

as previously noted, bored holes in the ice and planted poles at certain intervals, which required constant resetting to keep them in place owing to the rapid melting away of the surface. Recently steel plates about six inches on a side have been used, which lie on the surface and sink in slightly, thus securing a firm hold, and the motion over any stated period nearly indicates the motion of the ice below.

In 1899 a row of eight plates was laid out at a point about 1300 feet above the tongue. On the high right moraine the upper end of a base-line 229 feet 5 inches long was located, the lower end being further down on the same ridge. From both ends of this base-line all the plates could be seen, as well as most of the points on the ground moraine below the tongue. The center of a very prominent tree far up on the cliffs at the left side furnished the other end of the line on which the plates were laid out, a light mountain transit at each end of the base-line giving the locations without measurement on the ice. After thirty-six days the positions of these plates were noted and the amount they had moved from the straight line measured by means of a steel tape. These showed the maximum motion near the center to be 6.79 inches per day, and the minimum near the right side, 2.56 inches.

These plates were again measured in 1900, 1902, 1903, and 1906, when it was found that but one remained on the ice, all the others having fallen into crevasses and been lost or rested on the border moraine. The following table shows the total yearly motion, and the average daily advance from the period when the location was previously made:

ILLECILLEWAET GLACIER.—TABLE SHOWING MOTION OF LINE OF PLATES, 1899 TO 1906.

Number of Plate.	Position of Plates on July 31, 1899.	Distance below Original Line on August 6, 1900.	Daily Motion, 1899 to 1900	Distance below Original Line on August 26, 1902.	Daily Motion, 1900 to 1902.	Distance below Original Line on August 28, 1903.	Daily Motion, 1902 to 1903.	Distance below Original Line on July 12, 1906.
1.....	On line.	1044 ins.	2.82 ins.	3456 ins.	3.21 ins.	Lost.	—	Lost.
2.....	On line.	1488 ins.	4.00 ins.	4446 ins.	3.94 ins.	Lost.	—	Lost.
3.....	On line.	1716 ins.	4.64 ins.	4848 ins.	4.18 ins.	6216 ins.	3.73 ins.	On border moraine.
4.....	On line.	2112 ins.	5.71 ins.	Lost.	—	Lost.	—	10,200 ins.
5.....	On line.	2220 ins.	6.00 ins.	5850 ins.	4.84 ins.	7740 ins.	4.87 ins.	Lost.
6.....	On line.	2280 ins.	6.16 ins.	6312 ins.	5.51 ins.	8388 ins.	5.65 ins.	Lost.
7.....	On line.	2160 ins.	5.84 ins.	6504 ins.	5.79 ins.	Lost.	—	Lost.
8.....	On line.	2040 ins.	5.51 ins.	Lost.	—	Lost.	—	Lost.

These motions have also been plotted on the map and show graph-

ically the greater motion of the central portions, and that the right or concave side moves more slowly than the left or convex.

In the summer of 1906 a new row of six plates was laid out on the line of 1899, and after an interval of twelve days the maximum motion near the side was found to be 7.00 inches per day and near the center 11.33 inches. A comparison of the summer motion in 1899 and 1906, when tabulated in the following schedule, shows that the motion of the glacier at the present time is greater than it was in 1899, although less than the results of Dr. Green in 1888 would indicate. What effect this will have on the position of the tongue and glacier outline time alone will show.

TABLE COMPARING SUMMER DAILY MOTION OF PLATES ON ILLECILLEWAET GLACIER. 1899–1906.

1899—Thirty-six-Day Interval.			1906—Twelve-Day Interval.		
Number of Plate.	Feet from 1906 ice edge.	Average daily motion in inches.	Average daily motion in inches.	Feet from 1906 ice edge.	Number of Plate.
1	187	2.56	Plate lost.	92	1
2	415	3.90	7.00	276	2
3	520	5.51			
			11.33	532	3
4	668	6.77			
			9.75	727	4
5	760	6.06			
6	900	6.79			
7	956	6.16			
			10.25	1020	5
			8.85	1171	6
8	1220	6.00			

But one transit being available in 1906, the distances from the upper base-line ends to the plates were determined by means of a 12-foot stadia, the motions of the plates being of course measured with a steel tape. The very clear atmosphere made long sights satisfactory, but at times the vibration of the air, alternately cooled and warmed by the influence of the ice, made it necessary to wait a considerable time till this disturbance was removed.

Although a plotting of a map of the tongue and moraines of the glacier is a most important record of the conditions, but little need be mentioned here. The main points were determined by triangulation and the details sketched in with the aid of the transit and stadia. It may

PLATE 10.—TEST PICTURE FROM ROCK "W," 1899, ILLECILLEWAET GLACIER. (COMPARE PLATE 11.)

PLATE 11.—TEST PICTURE FROM ROCK "W," 1906, ILLECILLEWAET GLACIER. (COMPARE PLATE 10.)

be noted that the conditions change most rapidly even within a few weeks. Streams break through, while others disappear; on the ice crevasses open and close and great walls of ice form where before there were level plains. The 1906 plates were laid out on comparatively easy surfaces. Twelve days later great crevasses had opened between them; one plate was totally lost and several of the others were found in almost inaccessible positions.

A continuous photographic record of the tongue of a glacier supplies one of the most accurate means of comparison known. While annual

Plate 12.—Yoho Glacier, Field, B. C. Note the Ice Arch and Séracs.

changes, unless very marked, can only be determined after an interval of a number of years, the slight advance of crevasses and moraines may be distinctly seen, and after a term of say five or ten years, sweeping differences may be noted. On August 17, 1898, a large rock marked "W" on the map was selected from which the annual test picture might be made. Yearly from that time, at almost the same date, photographs have been made, using the same camera, lens, and as nearly as possible the same field of view. The trees in the foreground have grown, but the

tongue of the glacier is still unobstructed, and a comparison of these pictures at intervals of three or four years proves conclusively the continued retreat and shrinkage of the whole mass. (Compare Plates 10 and 11.)

It would be wearisome to recount the similar work carried on on

PLATE 13.—WENKCHEMNA GLACIER, ALBERTA. THE GLACIER IS ENCROACHING ON THE LIVING FOREST.

glaciers in the vicinity. The methods have been similar but varied to meet conditions.

The Asulkan Glacier, situated in the valley next to the Illecillewaet, receded since 1899, then advanced for a year, and the past summer (1906) was almost in the same position as in 1899. The summer rate of flow varies from 2.4 inches per day on the right side to 8.9 inches on

the left. It bears large masses of moraine and appears to be more active than its sister in the adjoining valley. (Frontispiece.)

Further to the east, at the boundary-line between Alberta and British Columbia, the great Yoho Glacier at the head of the Yoho Valley offers many features, particularly a superb ice arch, often sixty feet high and broad, from which the Wapta River issues. (Plate 12.)

The Victoria Glacier, above Lake Louise, is formed from the masses which avalanche from the upper slopes of Mount Victoria and fall 2500 feet to the secondary glacier below. The slope is very slight and the surface is so covered with a layer of moraine that the ice is obscured. Here glacier tables and sand cones may often be seen, while the surface characteristics are very marked. (Plate 1.)

In adjoining valleys the Wenkchemna and Horseshoe Glaciers are of marked interest. The former is of the piedmont type, being fed from a dozen smaller streams on the slopes of the Ten Peaks. This glacier exhibits unusual features in that it is probably advancing slightly and from year to year pushing its moraines over the living forest which surrounds it. If this be the case, it is the sole example of many scores of glaciers in the district which is advancing. (Plate 13.)

Descriptive details may be multiplied indefinitely, as no two glaciers exhibit the same characteristics. What has been said will, I trust, give a correct and pleasant idea of this great natural phenomenon, which if it has been successful will more than repay for this humble effort.

DISCUSSION.

Wm. C. Furber.—I would like to know something about the temperatures in that region.

Marshall R. Pugh.—I would like to ask what the present theories are in regard to glacier flow; whether Tyndall's regelation or Forbes' viscosity theory or some more recent, is the one held nowadays.

John C. Trautwine, Jr.—Votes of thanks to members are hardly in order, for it is the duty of each member to do all he can for the common entertainment, but I am sure my fellow-members will agree with me when I voice my appreciation of the interesting paper and beautiful illustrations which Mr. Vaux has presented to us.

Mr. Vaux's mention of the "red snow" reminds me of a remark made by Mr. DuBois in a paper referring to the same part of the world, wherein he described an adventure of his in coasting down a steep snow-covered slope. He was going so fast that objects near him on the snow appeared like streaks, and he was startled to see streaks of what he thought must be blood, and which made

him fear that he had somehow cut himself, and was bleeding to death. At the end of the coast, however, he discovered that his apprehension had been caused merely by the growth which goes by the name of "red snow."

Wm. S. Vaux.—The temperature of this region varies. During the summer it may rise to 75 or 80 degrees, but the latter is unusual. The winter, of course, is exceedingly cold in some districts. At Field, B. C., about midway between the Glacier House and the glaciers to the east, they have temperatures below zero for several days. In the mountains the temperature is not often exceedingly low; I would say from 5 to 10 degrees would be the minimum, but the snow-fall is very heavy. The snow-fall at the Glacier House will average 30 feet a year on the higher levels. The temperature is lower in the lower slopes than it is in the higher and more cloudy valleys.

Answering Mr. Pugh's question, I have purposely kept away from the theory of glacier motion, because I think it is very much like the "cement question." There are no less than nine different theories which have been advanced on the theory of glacier motion. It is now considered that the flow of glaciers is similar to the flow of water in a river and simply a question of gravitation of the ice masses. Tyndall and others have developed complicated theories to explain simple facts, but I have purposely kept entirely out of a discussion of this subject.

Paper No. 1038.

THE ELECTRICAL PLANT AND MEANS OF INTERIOR COMMUNICATION OF A MODERN OCEAN-GOING PASSENGER AND CARGO VESSEL.

CHAS. J. DOUGHERTY.

Read April 6, 1907.

Most engineers have some knowledge of the size and capacity of isolated electrical plants on shore, but, I am free to say, few, perhaps, realize what is being done today in the electrical line on modern ocean-going vessels.

On shore plants the generating units and switchboards are allowed ample space in the rooms provided for same, but on shipboard the poor electrical engineer is compelled to install his apparatus in as small a space as possible, and at times this space is totally inadequate for the proper handling of the apparatus. This crowding is necessary, however, for the vessel is a compact unit and every inch of space counts, so we are not allowed spacious quarters for the apparatus which forms the very heart and vitals of the electrical installation.

The plant which I shall describe to you this evening is installed on the new steamship "Momus," built by the William Cramp & Sons Ship and Engine-Building Company of Philadelphia. This vessel is for the Atlantic coastwise trade of the Southern Pacific Company of New York.

This company is building two vessels at the Cramp yard; the first vessel has been completed and is now in the New York-New Orleans passenger service. The second vessel, named the "Antilles," is rapidly nearing completion and is a sister ship to the "Momus."

The Fore River Ship and Engine Building Company, Quincy, Mass., has the contract for a third vessel similar in every respect to the "Momus" and "Antilles," with the exception of the propelling machinery, which consists of two screws, each operated by a Curtis steam turbine. This third vessel is named the "Creole."

The "Momus" and "Antilles" are single-screw vessels with reciprocating engines and Scotch boilers. All three vessels are steel and

of a type that has never been equaled before for coastwise service. They are deep-sea vessels of unusual strength and capable of navigating any waters of the globe, and their comfortable sea-going qualities, excellently arranged and airy passenger accommodations, large, roomy cargo holds, high speed, and beautiful models make them the undisputed peers of all coasting vessels.

I give herewith a brief description of the general dimensions and the internal arrangements of these vessels:

Length	440 feet
Beam	53 "
Depth	37 "
Low draft	26 "
Dead weight capacity	4,500 gross tons
Displacement	10,600 " "

The "Momus" and "Antilles" are each fitted with three double-ended and four single-ended Scotch boilers, the former being the largest boilers built in America.

These boilers are 15 feet 4 inches in diameter by 21 feet 4 inches long; they have eight furnaces each. The total grate surface is 770 square feet and the heating surface is 26,500 square feet. The steam pressure carried is 234 pounds. All boilers are connected to a single smokestack.

The steamship "Creole" is fitted with Babcock & Wilcox water-tube boilers, and superheaters are installed also, as this vessel is equipped with steam turbines for motive power and is of the twin-screw type. All three vessels having the same dimensions and displacement, this will enable the owners to settle for themselves the question as to the merits of reciprocating engines and turbine engines, as the results obtained in the economy of fuel, speed developed, and economy of maintenance can readily be compared.

The reciprocating engines of the "Momus" and the "Antilles" are of the vertical three-cylinder triple-expansion direct-acting marine type. Each vessel has one engine installed and it is of entirely new design. The diameters of the cylinders are as follows:

High pressure	34 inches
Intermediate pressure	57 "
Low pressure	104 "
The common stroke is	63 "

The cranks are set at an angle of 120 degrees with each other. The engine-bed plates are of cast-iron with heavy cast-iron housings sup-

porting the backs of the cylinders with wrought-steel forged columns in the front. The engine is designed to develop about 7000 H. P. when making seventy revolutions per minute with a steam pressure of 234 pounds at the boilers.

The valve gear is of the Stephenson type with double bar links working directly on the valve stem. The engine is also fitted with a floating lever reversing engine with an oil controlling cylinder bolted to the low-pressure housing. The turning engine for the main engine is a double-cylinder vertical inverted type located on the after engine-room bulkhead. There are six crank shaft bearings and six steady bearings. There is also a steady bearing at each end of the thrust bearing, forming part of this bearing. A main surface condenser is located on the starboard side of the engine-room.

Each vessel is fitted with a double bottom and the hull is divided into twenty-two watertight compartments. The vessels are especially constructed for handling cargo in the most expeditious and most economical manner. They are fitted with four overall hatches with folding covers and numerous sideports. The masts, although gracefully tapering and located with a pleasing rake, are really modern derrick posts, and practically all rigging has been dispensed with.

The cargo holds have a capacity for about 335,000 cubic feet of freight, or about 100,000 cubic feet more than any other vessel of the type at present afloat.

The coal bunkers will store 1700 tons of coal and the water-tanks will hold about 800 tons of water.

Each vessel carries a large refrigerating plant and cold-storage boxes for ship's provisions, also selected cargo spaces with a capacity of about four carloads of perishable freight.

The crew of each vessel numbers about one hundred and seventeen, twenty-three of which are allotted to the deck department, forty-six in the engine-room, and forty-eight in the stewards' department.

These ships are designed for a sea speed of 16 knots per hour, or about 18½ statute miles, and the speed is higher than the maintained speed of any vessel engaged today in American coastwise service.

The interior arrangements are worthy of a small description, but even this cannot do justice to the commodious and handsomely furnished interiors; so, therefore, I shall give only a brief outline thereof.

The first-class passenger accommodations are in the superstructure amidships, there being rooms arranged for the accommodation of one hundred and fifty-two passengers. All the state-rooms are outside

rooms—they are light, airy, well furnished, and comfortable, and it is to be noted that any part of the first-class passengers' quarters, including the dining saloon, library, smoking-room, barber shop, toilet-rooms, etc., can be reached from any other part of the vessel without the necessity of stepping out on deck, a convenience not always found on all first-class vessels.

Four luxurious suites are located on the upper deck. These suites consist of a parlor, bed-room, and bath. The dining-room on the lower deck is finished in pure colonial style in rich mahogany and it will seat all the passengers at one time.

The library is finished and decorated in Italian renaissance design with curly maple furnishings.

The smoking-room, bar, and barber shop are finished in oak, Flemish design.

The sanitary arrangements of the vessel are excellent; solid porcelain ware is used throughout and the sides of the toilet-rooms are lined with white marble.

On the aft quarter-deck are located accommodations for fifty-eight second-class passengers, and any number of steerage passengers, up to about five hundred, can be comfortably carried on the main deck forward.

The above description of these vessels may have seemed probably lengthy, but I feel that my audience should know the details and realize the excellent product turned out by one of Philadelphia's greatest industries, the William Cramp & Sons Ship and Engine-building Company.

The day of the oil lamp or candle bracket for lighting vessels is past. Modern vessels demand the use of electricity for lighting. These vessels which I have described with all their luxurious furnishings and joiner work would appear like dismal caverns were it not for the art of the electrical engineer in illuminating and beautifying their interiors. The incandescent lamp today plays no small part in the interior furnishings of vessels, and harmonious effects can readily be brought out or marred by poor lighting arrangements. The electrical plant, therefore, on one of these large passenger vessels is worthy of your consideration.

I shall now describe the electrical plant of the steamship "Momus," although the installations on all three vessels, it must be remembered, are exact duplicates.

GENERATING SETS.

The generating units are located in the main engine-room on the port side forward.

There are two 75 K. W. and one 10 K. W. sets installed. These sets are placed on a raised foundation equal in height to the first working platform grating of the main engine. The foundation consists of structural iron beams built up from the engine-room floor to the deck

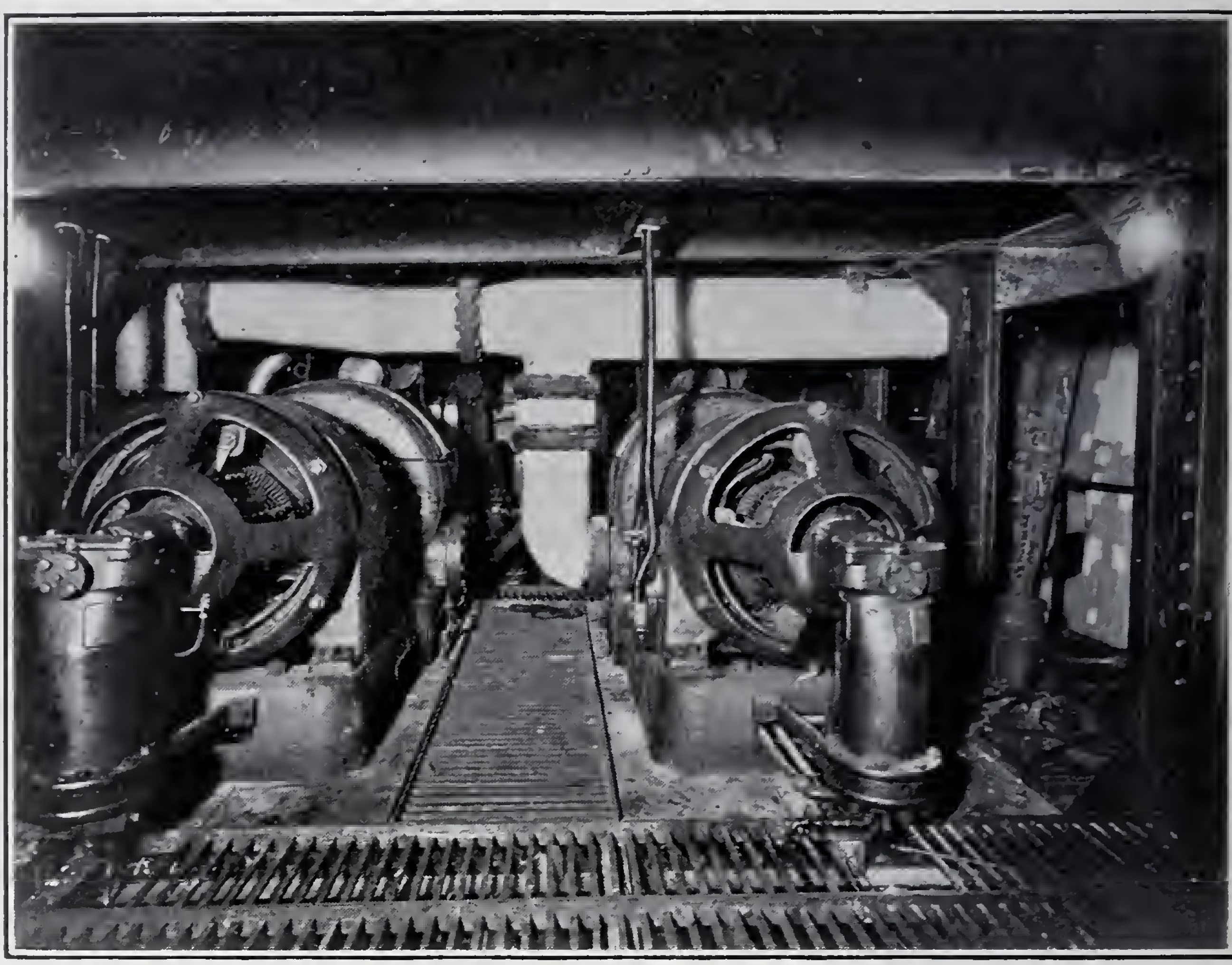


FIG. 1.—TURBINES IN ENGINE-ROOM.

above; heavy cross-beams join with these and run outboard to the vessel's side. A heavy steel plate the shape of each generating set base is fastened to the steel structure as described and forms a rigid and non-vibrating foundation. Considering the high speed of the large generating sets, no vibration is noticeable when these sets are running up to full load and full speed.

The small 10 K. W. generating set is a General Electric Co. marine type, 110-volt, direct-connected, with single cylinder engine and forced lubrication. This set is installed to take care of the ordinary day

load of the vessel when at sea, and it can also be used when the vessel is discharging cargo at the docks. The set runs nicely and meets all the conditions for which it was intended. The 75 K. W. sets probably will interest you the most, as they are steam turbine sets.

A Curtis steam turbine is directly connected by means of a flexible coupling to a General Electric Co. direct-current generator. You will note that the turbine is of the horizontal type and the turbine and generator are each equipped with two bearings and the set is assembled on a rigid bed-plate which is cast all in one piece. Great care is taken in lining up these sets, as a very slight non-alignment will produce serious vibration troubles.

The turbine is of the two-stage condensing type, each stage having two bucket wheels and one set of intermediate or fixed buckets.

The nozzles are machined from solid castings and, being carefully lined up during assembly, do not require adjustment. Between stages is a water separator, the drip from which is piped to the vessel's bilge. Steam is admitted to the steam chest through a combined throttle and emergency valve, and from this is distributed to the several first-stage nozzles through governing mechanism.

The turbines operate at a speed of 2400 revolutions per minute and are supplied with steam at 230 pounds pressure. The high speed of operation makes the question of lubrication a very interesting one. All working parts of the valve gear, including the oil reservoir on the hollow governor lever, are oiled by hand. The hollow governor lever is filled with 600-degree cylinder oil, and this is done once a day.

The main bearings of the machine are furnished with forced lubrication from an oil pump on the end of the generator shaft. This pump contains two independent systems, one for the bearings and one for the valve mechanism. The relief valve for the valve-gear pump should operate at about 80 pounds and the one for the bearings at six to ten pounds. Gages for both systems are supplied with each set. All four pillow blocks are provided with auxiliary oil wells and rings. The bearings are of the self-aligning, ball-seated, babbit-lined type and are made in halves. The end-play of the turbine shaft is limited at each end of the governor and bearing by a roller thrust bearing and the end-play is about 0.015 inches. The speed regulation of the turbine is maintained by varying the number of first-stage nozzles in action to the proportion of the variations of load, steam being admitted independently to the several nozzle bowls through four plain poppet type valves.

Perhaps the most interesting part of the steam turbine would be to describe to you the governing mechanism, but I will say that this would require a lengthy and intricate detail, and the length of my paper will permit me but to simply touch upon it.

The governor consists of a pair of adjustable weights acting on a tension spring; all movement is borne upon knife-edges and a slight adjustment of speed may be made by means of a spanner nut. The governor spindle terminates in a hardened steel ball which runs in phosphor-bronze ball seats in the governor lever. The working travel

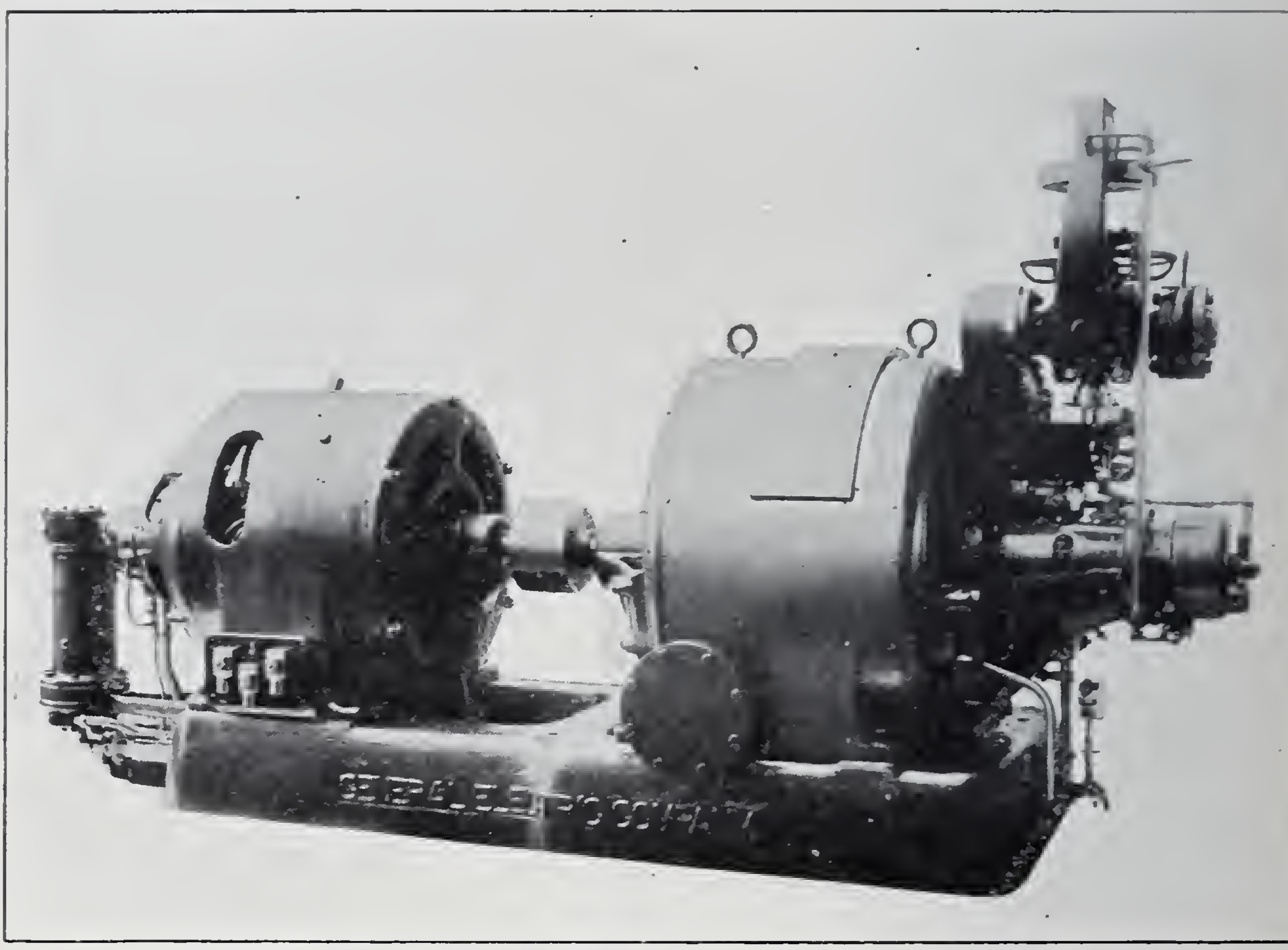


Fig. 2.—Seventy-five Unit as Installed on the Vessel.

of the governor spindle, that is, the travel necessary to open or close all valves, is $\frac{3}{8}$ inch and the total travel available is $\frac{1}{2}$ inch. The essential feature of the valve-governing mechanism is a hydraulic plunger principle governing a pilot valve, which in turn operates the poppet valves to the nozzle bowls. Each turbine has two emergency governors mounted on the outer governor ring. They consist of a spiral or clock spring, the free end of which flies outward at a speed of 2600 revolutions and trips a trigger. This tripping of the trigger releases a weight, which closes the main throttle valve. This valve is of the poppet type,

the spindle being moved up or down by a hand-wheel through two sets of toggles joining a hand-wheel to a yoke on the valve spindle.

The General Electric Co. experienced considerable trouble at first with the shaft packings on these 75 K. W. sets. It is to be remembered that the operating steam pressure is 230 pounds, and the speed of the shaft is 2400 revolutions. These are the two fixed quantities and the shaft packing was the unknown one. After much experimenting it was found that the best results were obtained from carbon.

The above covers the description of the turbine part of the set, but there is another side to be considered, that is, the operation and efficiency of these turbine sets, and I will now briefly give you these data.

These turbine sets are guaranteed by the General Electric Co. to have a speed regulation of 2 per cent. from no load to full load with a momentary permissible swing of 4 per cent. with sudden large variations of load. The governor can be adjusted to give a closer range, but this is not advisable, as it makes the governing mechanism more delicate, and, consequently, not as stable.

The turbines were designed for 250 pounds steam pressure, but as the highest steam pressure available for testing purposes at the Lynn Works of the General Electric Co. was 175 pounds, the steam consumption readings which were taken on test had to be corrected to 250 pounds pressure, this being the requirement of the guaranteed specifications.

With 250 pounds steam pressure, 28 inches of vacuum, and 100° F. superheat, the steam consumption at full load was 24.5 pounds. This figure is equivalent to about 16.5 pounds steam per break horse-power under the conditions given. The 24.5 pounds at full load is expressed in pounds per kilowatt delivered at the generator terminals, assuming the generator efficiency at 90 per cent., which is approximately correct. The generators connected to the turbines are of the latest and most approved General Electric Co. type. They have four poles, are compound wound, the voltage is 110, and they are equipped with two commutators on account of the brush friction due to the high speed of the set. The brushes are specially treated by the General Electric Co. and they are of the carbon type, and they advise that these brushes be not replaced by brushes of other make without first being advised by them. The generators met the temperature guarantees of 45° C. maximum rise for twenty-four hours full load and 60° C. rise after two hours at 25 per cent. overload, the room temperature being based on 25° C.

I believe these turbine sets are the first installation of the kind on merchant vessels for coastwise trade, and I am pleased to state that they have given excellent results in practical operation on the steamship "Momus."

The switchboard is of white marble and consists of three panels; the outside panels are for the 75 K. W. sets and the center panel for the 10 K. W. set. The panels are securely bolted to an angle-iron framing and the weight of the board is entirely taken by cast-iron pedestals, four in number.

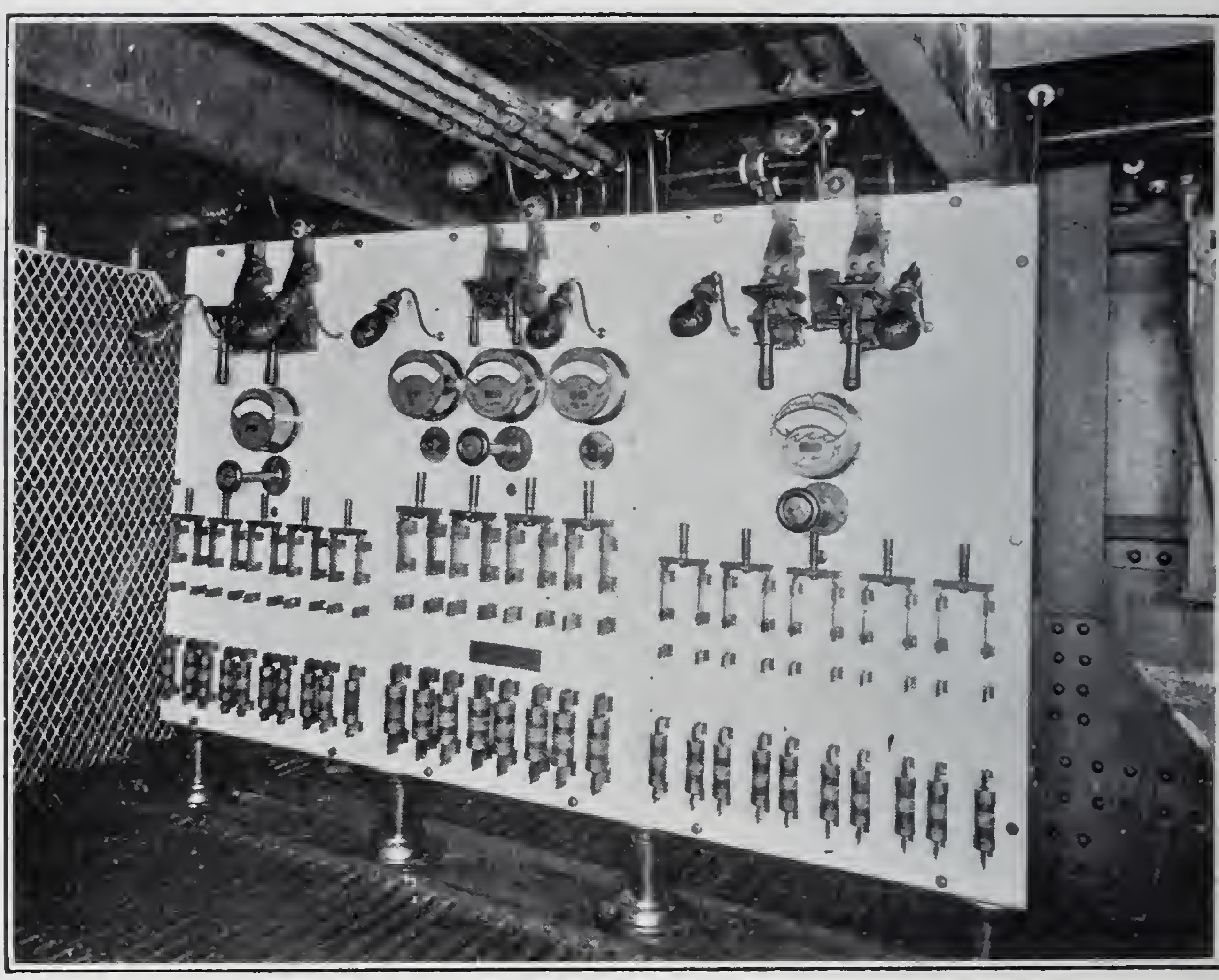


FIG. 3.—SWITCHBOARD.

Each dynamo has an overload circuit breaker mounted at the top of the panel and the necessary indicating instruments, such as ammeters and voltmeters, are installed.

There are fourteen feeder switches, ten 200 amperes and four 300 amperes capacity. These are the double-pole, double-throw type with enclosed fuses at the bottom of the board.

The two 75 K. W. sets are arranged to operate in parallel and they are connected to one set of bus bars. The 10 K. W. set is connected

to an independent set of bus bars. Therefore any circuit can be connected to the 75 K. W. sets or to the 10 K. W. set as may be desired. It is, however, to be remembered that when the 75 K. W. sets are in operation, the 10 K. W. set is usually shut down.

There are five lighting feeders, one searchlight, one cargo circuit, one ventilation, and four heating circuit feeders. The bus wires for the 75 K. W. sets consist of 1,000,000 cm. cable.

As the space allotted to the switchboard is very small, it was necessary to crowd the apparatus, and the equalizing switch for the 75 K. W. sets was not placed on the switchboard, but on the side of one of the above mentioned sets.

There are no other special features on this switchboard which are worthy of mention.

A searchlight is a necessity on board a coastwise vessel, and the importance and usefulness of this piece of electrical apparatus is not overestimated. It serves to pick up buoys in channels, to signal between vessels at sea, and is very useful in the vessel making a dock at night-time—in fact, its value is always appreciated by up-to-date captains.

This vessel is equipped with a 24-inch searchlight with pilot-house control and is of the General Electric Co. make. The light is installed on top of the pilot-house and projects a beam of light of sufficient density to render plainly discernible on a clear, dark night a light colored object 10 by 20 feet in size at a distance of not less than 5000 yards. The lamp produces the best results when taking about 50 or 60 amperes of current. The lamp is of the horizontal carbon type and is designed for both hand and automatic feed. A rheostat is used to cut down the voltage from 110 to about 45 volts, and this rheostat is located back of the main switchboard. After this rheostat is once set to give the correct amperage of the lamp it need not be adjusted.

Fixtures.

In the state-rooms, saloons, library, smoking-room, and passenger quarters special ornamental fixtures are installed, and the design and finish of these fixtures harmonize with the interior furnishings.

Special attention was given to the library and smoking-room fixtures. These were designed with special reference to the general style of these rooms, the library being on Louis XVI style and the smoking-room on the Dutch or Flemish.

In the steerages, engine-rooms, fire-rooms, cargo holds, and all places

where there is any moisture or exposure to the weather, fixtures with a steam-tight globe and a heavy protecting guard are installed.

The vessel is wired throughout on the two-wire system and feeders from the switchboard connect to panel boards located on the different decks. These panel boards are of two types, namely, non-watertight and watertight; the former are located in the passenger spaces and the latter in the steerages and machinery spaces.

The panel boards are of slate, and circuit switches, double-pole type with enclosed fuses, are mounted thereon.

The non-watertight panel boards are incased in hardwood closets with slate side linings and present a very neat appearance in the rooms where they are located.

The watertight type of distribution panel is something special and it is our standard design. The encasing metal of the box is cast-iron or brass and the cover on the face is made absolutely watertight by means of a soft-rubber gasket placed inside a groove designed for it. The various circuit leads run out from this box in conduit and the feeder to the bus bars comes in from the bottom and is also in conduit.

The panel boards are the distributing centers for the lighting circuits in the immediate vicinity and not over twelve lights are installed on any circuit leading therefrom.

The drop in volts to the farthest lamp does not exceed three, and all feeder wires are figured on a basis of 1000 cm. per ampere carried. No wire smaller than No. 14 B. & S. is used, and all wires over No. 12 B. & S. are stranded. The highest grade of rubber-covered wire was used and the insulation of the wire consisted of a white compound next to the conductor, then a 30 per cent. best grade Para vulcanized compound over this, a tape, and two woven braids.

Moldings are used in the living spaces, but in special cases the wires were encased in flexible woven conduit. This was done behind panel work or where it was impracticable to run either molding or conduit.

In the engine-rooms, fire-rooms, cargo holds, and in all exposed places, galvanized iron enameled conduit, known by the trade name of "Galvoduct," was installed. The necessary junction boxes, outlet receptacles, switches, and wiring accessories required for the conduit system were supplied from our regular stock.

In the state-rooms the switches for turning off and on the lights are of the flush type such as we find in ordinary high-grade house wiring, and they represent a very high grade. Therefore you are to

note that every convenience of the passenger was carefully considered in detail.

Government and insurance regulations require vessels to display certain signal-lights between sunset and sunrise. Vessels provided with an electrical plant have installed running lights equipped with incandescent lamps. Electricity is peculiarly adapted to the illumination of ships' running lights, since it furnishes a ready means of providing an indicator or tell-tale which will both visibly and audibly indicate when the incandescent lamps installed in the running lights are accidentally extinguished.

The port, starboard, mast-head, and range lights are connected to a tell-tale board. The board consists of a piece of black enameled slate and has mounted on it, for each running light connected, a snap switch, bell, and a single-pole double-throw switch. The terminals at the bottom of the board are connected to the lighting mains and the snap switch controls the current to the running light circuit, which is connected to the upper terminals on the board. To avoid the inconvenience of replacing lamps inside of the running lights when in storms or rough weather, the running lights are equipped with two incandescent lamps, one of which burns and the other acts as a reserve to be thrown into circuit in case of a "burn out." The tell-tale board is, therefore, designed to take care of two lamps in each running light. The extra or reserve lamp is readily connected in circuit by means of a small knife-switch at the top of the board. This can be thrown either to the right or the left, connecting the corresponding lamp in circuit. If at any time when current is on the main wires and the running lights are in circuit and burning, the lamp in the running light should go out, the indicator lamp on the tell-tale board will light up and the bell will also sound, thus giving immediate warning that this particular running light is extinguished.

Electric Heating System.

The passenger accommodations on these vessels are entirely dependent for heat upon electric heaters—there is nothing else to take their place. The electric heaters, therefore, are a very important piece of apparatus on these vessels as far as the passengers' comfort is concerned.

The electric heaters are rather a bold and unprecedented departure from the regular practice in vogue at present, namely, steam heating. But the electrical engineer has caused the steam engineer, to use a slang expression, "to sit up and take notice." The Superintending

Engineer of the Southern Pacific Co. is entitled to the credit for this radical change in the heating system on these vessels. It must be acknowledged that electric heaters are superior to steam radiators in that they are more compact, weigh less, are much neater in appearance, more easily regulated, and last, but by far not least, they have no liquid to leak out. The heaters have proved themselves a success on these vessels and every one is highly pleased with them. Of course, we all know how easy it is to decide upon a new system, but when it comes down to actually selecting a piece of apparatus best suited for our needs—well, this is another story. There are many good electric heaters on the market, but after looking them over we decided that none of them actually suited the particular case.

Knowing the unlimited resources of the General Electric Co. and the high grade of engineering talent employed, we modestly put the problem of design for these electric heaters up to the heating engineering department of that company, and we only made a few skeleton ideas for them to work upon. Therefore I take great pleasure in showing you this evening the result of this company's labor.

The heating element is of a design known as the "cartridge unit," and it consists of a coil of edgewise wound German silver resistance ribbon enclosed in a brass casing. The coil is insulated from the casing by a covering of sheet mica and the turns of wire in the resistance coil are insulated from each other by means of an anhydrous mixture. This mixture is generously filled in between the turns, after which the coils are baked in a gas oven so that the mixture adheres firmly to the coil and forms a desirable insulator. The coil is then placed in the casing, the open ends of which are spun over a porcelain bushing. The bushing is thus held firmly on the end of the coil and the whole forms a strong construction. Internal leads from the ends of the coil project through the porcelain bushing and form a means of electrical connection to the unit. The outside of the unit casing is equipped with radiating strips of metal ribbon, which serve to dissipate the intense heat generated in the coil, which, I am informed, rises to 500° or 600° F.

The 750 watt heaters (Fig. 4) consist of two sections, each 4½ inches long, and have a hot resistance each of 32.4 ohms. These sections are assembled together end to end in the coil casing and German silver leads are brazed to their common juncture and to each end of the combined coil. By this means the two sections of the coil may be connected in series, one section alone or the two sections in multiple, thus giving the three degrees of heat called respectively "low," "medium," and

"high," and corresponding in watts to 187, 375, and 750. The five-point heater switch for controlling these heaters is located at any convenient position on the state-room bulkhead. The switch is of the indicating dial type and gives the indications "low," "medium," "high," "off."

Fig. 5 shows the large size or 1800 watt heater, and these are located in passageways, in the main dining saloon, and other places where there is a large volume of air to be heated.

The heating units of the 1800 watt heaters consist of two coils, each 9 inches long, and they have a hot resistance of 13.45 ohms. The connections and operation of these coils are exactly similar to those of the 750 watt heaters which I have described, with the exception that the

Fig. 4.—Seven Hundred and Fifty Watt State-room Heater.

coils are assembled in separate casings with a metal shoulder at their common juncture.

The state-room heaters, which are 750 watts capacity, are mounted on the bulkhead and insulated therefrom by a pad of transite board, which acts as a heat-insulating material. It was found necessary after these heaters were installed on board the vessel to place Russia iron shields over them in the state-rooms to prevent dust, and particularly the passengers from throwing refuse on top of the perforated casings, as the intense heat of the heaters probably would start a fire, for when these heaters are running up to full heat, or 750 watts, the unit shows a very dull-red color; consequently you will understand that they are fairly hot, and particles of paper or refuse should not be allowed to come in contact with them, otherwise probably a fire will start, hence the necessity of placing shields over them.

On the trial trip of the steamship "Momus" an accident such as this did actually happen. One of the guests threw a pillow over the heater in his state-room, and in a very short time there was some smoke and a bad odor of burning feathers from this particular state-room, and. I may remark, also a very badly scared man, who was the occupant of the state-room.

Both sizes of electric heaters are neat in appearance and are exceptionally compact. The 750 watt heater measures $14\frac{1}{2}$ inches long, $4\frac{1}{2}$ inches wide, and $4\frac{5}{8}$ inches high. The 1800 watt heaters are 26 inches long, $14\frac{1}{2}$ inches wide, and $4\frac{1}{2}$ inches high. Both of the heaters have

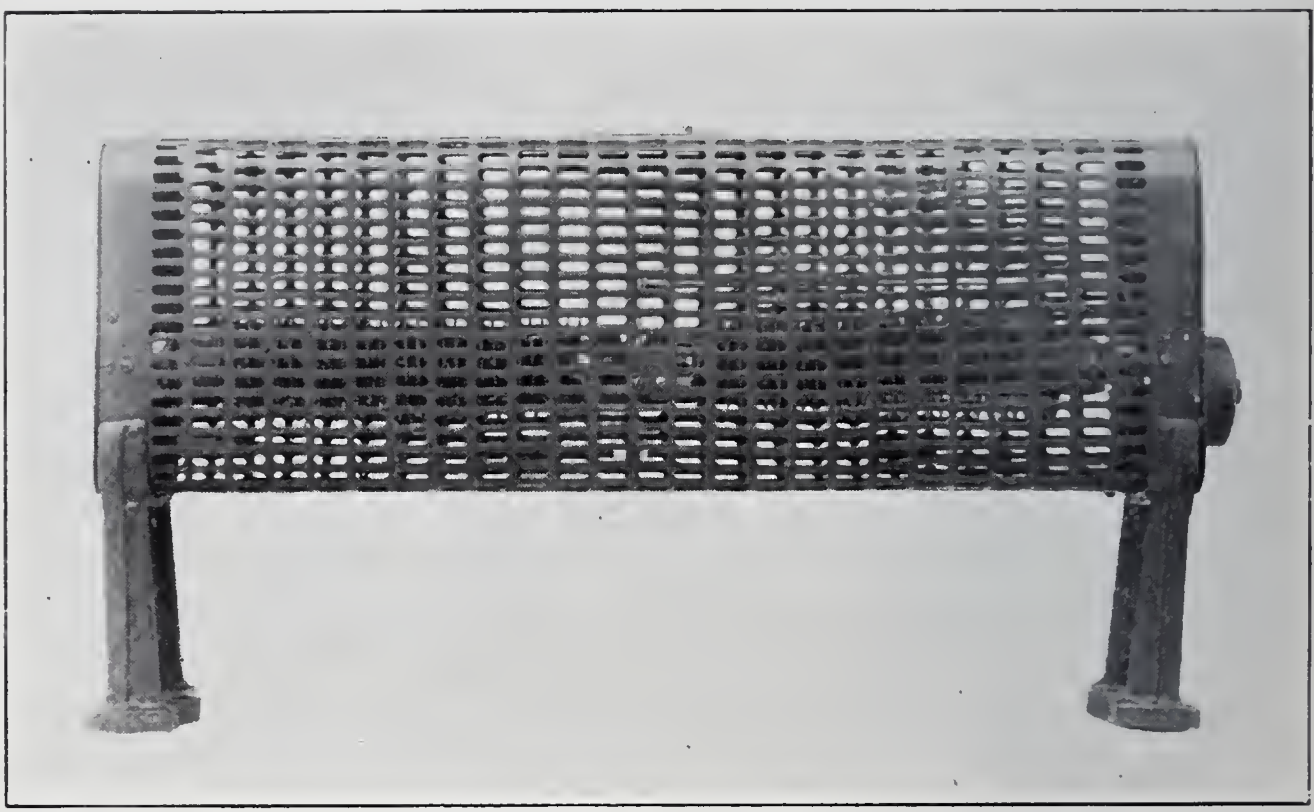


FIG. 5.—EIGHTEEN HUNDRED WATT HEATER.

perforated covers. These covers are made out of heavy-gage metal and will withstand any ordinary amount of abuse or injury.

Descriptions of apparatus are always interesting, but what everybody wants to know is, how well do these electric heaters work and do they really heat? I quote herewith an extract from the report of the representatives of the builders on board the "Momus" on her maiden trip from New York to New Orleans:

"When we left New York the thermometer was 15 degrees above zero, and the morning the vessel sailed she was as cold as an ice-house, for the reason that the ship's stewards had not turned on the electric heaters. By the time we were outside of Sandy Hook the vessel was

well warmed up. This was a severe test of the heating system and the electric heaters proved themselves capable in every respect. The weather moderated very materially, and by Saturday the thermometer

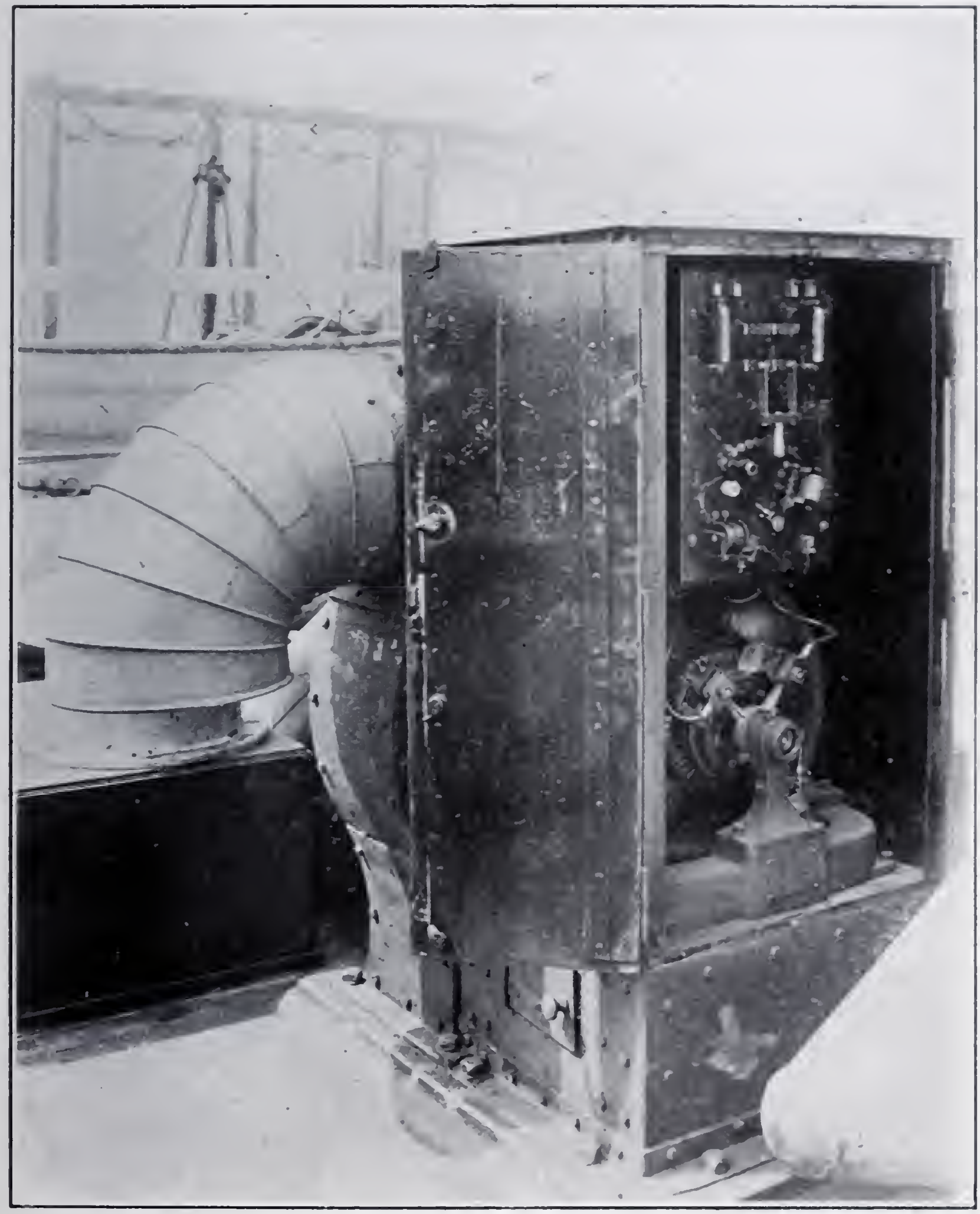


Fig. 6.—Forty-inch Ventilating Sets.

outside was up to 80°, so that after two days out the heaters were not used."

There are one hundred and twenty-four 750 watt heaters and forty

1800 watt heaters installed on each vessel. The heaters are capable of heating the vessel in the coldest weather and there is no inconvenience of heat from steam-pipes when the vessel is in southern waters. This is something in itself which is worthy of consideration, and, in my opinion, the electric heater is the only one to install on a vessel whose voyage involves a change of climate, hot to cold, or vice versâ. Steam radiators may soon be a thing of the past on shipboard.

In the first and second cabin dining saloon and in some of the passenger suites direct-current fan motors 18 inches in diameter are installed. These fans were of the Sprague Electric Co. make, and there is a special wire guard placed over the lower half of the fan. This is to prevent any one being injured while the fan is running. Such accidents have happened and have resulted in heavy damage suits to vessel-owners.

For ventilating the smoking-room and the first-class toilet-rooms there were installed two 40-inch Sturtevant steel plate type fans, motor driven. These were placed on top of the deck-house aft.

Your attention is called to the watertight casing around the motor and the controlling panel. This casing must be absolutely watertight, as the set is located in the open and everything must be accessible and yet absolutely watertight.

The dish-washing machine and the ice-cream freezer are located in the pantry and these are operated by electric motors. These machines require no special description, as they follow the standard practice of installation, which I am quite sure is familiar to all.

Means of Interior Communication.

Most of us are familiar with the electric lighting of vessels. We all must recognize that modern vessels are equipped with lighting plants, but how many of us know anything about the means of interior communication on shipboard? The up-to-date first-class vessel is nothing more than a floating hotel complete with all the conveniences which one expects to find in a first-class hotel; therefore I believe that the following description of what constitutes the interior communication on a vessel will prove of interest.

On this vessel the following interior communication systems are installed:

Call bells.
Fire-alarm.
Telephones.
Mechanical telegraphs.

Whistle operator.

Wireless telegraph.

Push-buttons are installed in the public rooms and in all first-class and second-class state-rooms. Each button connects by wire with a marine-type needle-point annunciator.

This annunciator is located in the pantry. There are about one hundred and sixty buttons installed and each button requires one wire to be run back to the annunciator. The amount of bell-wire for this system alone is five miles. You will, therefore, realize that the call bell system in itself is not a very small installation.

Perhaps one of the most important systems on the vessel is the fire-alarm or fire-detecting system. The necessity of an instant fire-alarm cannot be overestimated; in fact, only one service can exceed it in value—that which forewarns of the approach of fire, that which gives notice that the temperature has risen dangerously near the point of ignition. The latter service is one which the thermostat is expected to render, and the type of apparatus which does it I will now describe.

After carefully looking over the fire-detecting apparatus at present on the market we decided to adopt the type of fire-alarm thermostat manufactured by the Montauk Fire Detecting Wire Co. of New York. This fire-detecting wire unit can best be described as follows:

A copper conductor is coated first with a fusible alloy; second, with a concentric insulation; third, with a concentric conductor. The core conductor is connected in series with a battery, annunciator and concentric conductor. This forms the circuit. The circuit remains open as long as the concentric insulation is intact. Now the effect of exposure to heat higher than the critical temperature of the alloy is to cause it to fuse, and in fusing to expand. This expansion results in numerous radial lines of alloy being forced through the surrounding insulation. As this insulation contains a fluxing compound, the alloy unites in a soldered connection with the concentric conductor, thus perfectly closing the circuit at many points.

The above covers the principle of the apparatus adopted by us, but owing to our special requirements for the thermostat system on this vessel, a special tube thermostat was designed. The fire-detecting wire as described is bent into the shape of a horseshoe, and the ends passed into the cover of a porcelain receptacle.

Within this cover the core wire is permanently connected with the base of one binding post and the outside tube connected with another post.

The interior of the cover is then filled with an insulating compound and the cover is sealed into a porcelain base. The thermostats are made to operate on a temperature of 160° or 200° F., and the porcelain base is colored red or green to distinguish the two temperature ratings. The thermostats are wired in multiple and are enclosed in steel outlet boxes with covers. This is necessary to prevent injury to them, as they are installed in the cargo holds and are subjected to more or less hard handling. All wires for thermostats are carried in iron conduit and the thermostats throughout the cargo holds connect to a special fire-alarm watertight type of annunciator located in the main engine-room.

The thermostat system as installed on these vessels is very simple and is exceedingly reliable.

Those of us who have traveled much on steamers can appreciate the necessity of having a prompt and absolute means of communication between the navigating department and the engine-room department on board a vessel. Thus far I have described the apparatus mainly for the comfort and convenience of the passenger, but now I come to the most important part of all—intercommunication between captain and chief engineer and the navigation of the vessel.

Telephones are now recognized as superior to speaking-tubes, as these speaking-tubes are usually long, have many bends, and the voice does not carry very well. The telephone, therefore, is preferred if it is of a good make and constructed to take care of the special loud-sounding requirements for shipboard.

On the "Momus" telephone communication is arranged between the pilot-house, engine-room, chief engineer's state-room, and the warping bridge aft. Where the 'phones are exposed to weather conditions a watertight type of telephone was installed. This telephone is the same as is used in the United States Navy practice. In the pilot-house and in the chief engineer's state-room non-watertight telephone sets are used. These telephones are all of the loud-sounding type and give excellent results in service.

The means of sending orders from the bridge to the engine-room and a reply from the engine-room to the bridge is commonly known on shipboard as a mechanical telegraph system. This system is divided into the following parts:

Engine telegraph.
Sounding telegraph.
Steering telegraph.

Anchor telegraph.

Docking telegraph.

The transmitting instrument of all the above systems, with one exception, is located on the bridge or in the pilot house, and orders are sent from the transmitters to the receivers located throughout the vessel.

These telegraph instruments are connected by wires to handles and indicating arrows in the instruments, and when a signal is sent by the transmitter an arrow points on the dial to the particular signal sent, and the reply is received back from the receiving station on the same dial by a reply arrow. Thus when the transmitting instrument shows that the two arrows are on the same indication, the captain understands that his orders have been understood.

These mechanical telegraphs are very important on vessels, and too much care cannot be exercised in installing them, for a failure of the apparatus when the vessel is in a tight place might mean an accident, such as a collision, etc.

A very convenient and useful piece of apparatus called the "electric whistle operator" is now installed on all vessels which have any pretensions whatever of being called up-to-date.

The operator consists of a valve operated by an electro-magnet, and it can also be operated by hand; a clock-work mechanism by which a contact is kept closed automatically for six seconds in every minute; a switch by which the valve is controlled from the bridge or other locations as may be desired. The magnet is placed in a watertight metal case alongside of the metal valve. The controlling switch for the bridge is of watertight construction and is adapted for mounting on a bulkhead or bridge rails. The movement of the switch lever to the first point gives a closed circuit for a continuous or at-will blast. For automatic signaling a clock mechanism mounted in a metal case and installed in the pilot-house automatically closes the whistle valve for six seconds in every minute, and this signal is used when the vessel is under way in a fog.

The clock is an eight-day movement with practically all parts made of non-oxidizable metal, and you will note the binding posts located on a contact block alongside of the clock, and to these binding posts circuit wires are led from the whistle valve and the controlling switch on the bridge. Current is supplied for operating the whistle apparatus from the lighting mains at 110 volts.

These operators will work satisfactorily 20 volts above or 20 volts

below the normal voltage, and the valve operates on full boiler pressure up to 300 pounds. All contact points are of platinum of ample size for continual service, and all breaks are of the double-pole type.

The apparatus is very simple and requires no other attention than to wind the clock once in eight days.

A Nicholson ship log is installed on the vessel and it is a radical departure from all other types of nautical measuring devices. In addition to giving the mileage sailed, it shows the speed per hour on a dial and records this speed on a paper record chart for every minute of the trip. These records can be dated and filed away for future reference, and should any accident or controversy occur they would furnish incontestable evidence.

When adjusted to the ship the log will run the distances as close as it is possible to steer the vessel, and will remain in adjustment an indefinite period if intelligent care is given to the apparatus. The whole apparatus is entirely automatic, and it requires very little attention beyond the daily winding of the clock and the changing of the paper records.

For taking soundings of the vessel there is installed a Kelvin deep-sea sounding machine.

This completes the equipment directly connected with the navigating department of the vessel.

The necessity for having communication with the shore and with lightships when the vessel is at sea is recognized, and it is now the universal practice on all first-class vessels to install a wireless telegraph outfit, and as these vessels of the Southern Pacific Company are thoroughly up-to-date in every respect, special attention has been given to the installation of a wireless telegraph outfit, and this outfit was supplied by the American De Forest Wireless Telegraph Company of New York.

In concluding this paper I desire to present for your consideration a few items which I feel may be of interest in connection with the electrical outfit:

No. 1.	The total number of incandescent lights installed on the vessel is....................	900
No. 2.	The total number of thermostats for fire-detecting device is.......................	160
No. 3.	The total number of push-buttons for the call-bell system is........................	160
No. 4.	The number of electric heaters installed is . .	175
No. 5.	The total weight of the electrical plant and means of interior communication is........	48½ tons

No. 6. The number of miles of copper wire in the electrical plant, including lighting, power, and heating systems, is	10½ miles
No. 7. In the call-bell, thermostat, and telephone systems the number of miles of copper wire is	10
No. 8. The amount of conduit installed on all systems is	20,000 feet
No. 9. The total kilowatt output of the generators under normal full load is	160 K. W.
No. 10. The total connected kilowatt load of electric heaters installed on the vessel is	160 K. W.

From the above data you can appreciate that the electrical installation on board these vessels is of some magnitude, and we would necessarily expect to find at least a competent electrical mechanic devoted entirely to looking after this plant, but I regret to say that the whole plant is under the care of the chief engineer of the vessel, and there is no electrical man on board to look after the installation. I feel quite sure that in a plant of this magnitude on shore we would find a competent man devoted to taking care of it, but the particular point which I desire to bring out is that the ship-building company performing the work of installing the electrical system must do their work in a very careful manner, and the work itself and the material used must be of the highest class. For on shore we have means at hand to enable us to make repairs, but on shipboard, after the vessel is at sea, the facilities and the talent employed for such repairs are not always of the highest class.

I trust that I have been able to make you all better acquainted with the important part which electricity plays on the modern merchant marine vessel.

DISCUSSION.

E. M. Nichols.—You spoke of having a sheet-iron shield, at what distance above the heater? Was there any test made to find out how many heat units in steam delivered at the turbine were effective at the heater? I would also like to ask a question concerning the heater. In how large a room was the heater installed? Granting that a 750 watt generator is supposed to be equal to one horse-power, in steam heat that would mean 100 square feet of heating surface, which will heat twenty rooms 6 feet by 8 feet.

Chas. J. Dougherty.—The shield was placed about two inches above the heater; it is nothing more than a Russia iron shell, and turned over. In regard to the test you speak of, it has never been tried. The room in which the heater was installed is about 6 feet by 8 feet. We do not claim that electric heating is to be compared with steam heating; but our point is, that we have not the ugly coil of excess steam pipes that you have in your steam system, which are un-

sightly, and rather expensive at that. Our point is, that it is economical in the sense of space; it will not leak, and we cannot keep steam pipes from leaking on board ship. Then again we have carpets, and leaky steam pipes are apt to cause trouble where you have carpets.

Carl Hering.—In connection with Mr. Nichols' criticism, namely, that the quantity of steam consumed to supply these electric heaters with current is greater than that used in direct steam heating, I desire to remark that if this steamer was intended for trips to the northern regions, where the heat would be likely to be turned on for twenty-four hours a day, instead of going to the southern regions, where it is likely that the heaters would be turned on only for a short time to take off the chill, electric heaters would probably not have been used. The great advantage of an electric heater, which should not be overlooked, is that you can get heat very quickly, and when you turn it off, there is absolutely no waste heat to be paid for, such as in the condensation in the network of steam pipes leading to a larger number of individual steam heaters. The advantages of an electric heater are not in the amount of heat generated in the air of a room per pound of coal in the boiler, except under certain circumstances; the advantages lie chiefly in other directions, like convenience, absence of plumbing and its attending repairs, etc. They have been discussed so frequently that it is not necessary to repeat them here; I merely wish to emphasize that the efficiency in pounds of coal per square foot of heating surface is not necessarily a criterion, as there are many other considerations which also have a money value.

I do not know the reasons why the heaters in this case were made so small and heated to so high a temperature, but unless there are good reasons, it does not seem to me to be the best practice to heat the heaters to such a high temperature. The efficiency of the conversion of electric energy into heat energy in electric heaters is always 100 per cent., or virtually so, and therefore the only advantage I can see in using small heaters at high temperature, instead of larger ones at lower temperature, lies in the lower first cost. Against this, however, are the probably much more rapid deterioration, the danger of fire by the ignition of inflammable material in coming in contact with them, and the odor of burnt air. Without going into any calculations, it seems to me it would have been cheaper, in the end, had the heaters been made somewhat larger and were run at a lower temperature.

Mr. Meyers.—What provision has been made on board ship for lighting, in case the electrical apparatus gets out of order, particularly for the starboard and port running lights that are so necessary?

PAPER NO. 1039.

OBSERVATIONS ON SOME PHYSICAL CHARACTERISTICS OF CAST-IRON.

JAMES CHRISTIE.

Read April 20, 1907.

CAST-IRON is probably the most complex, variable, and uncertain form in which iron is used. Not only is the content of extraneous metals and metalloids variable, but the condition in which the associated carbon exists, and the character of this association, are determined largely by the influence of silicon and possibly other metalloids. Again, the physical properties of the metal are influenced by casting temperature, rate of cooling, etc., so that altogether we can only predicate the probable strength and stiffness of a casting in the most general way, and forecast results, which will suit an average, from which individual castings may vary widely in extremes. Gray iron of the foundry grades is alone considered here. The grading of the pig metal at the furnace has been, in the past, determined by the appearance of the fracture, but recently as much of the product is run in metal moulds, and appearance of fracture is deceptive, the tendency is to grade by chemical composition, the softer and weaker metals having the highest silicon and the lowest percentage of combined carbon. Taking three grades of foundry pig and assuming that these are used for different classes of castings, say:

No. 1—2.5 to 3 per cent. silicon for light castings.

No. 2—2 to 2.5 per cent. silicon for medium-weight castings.

No. 3—1.5 to 2 per cent. silicon for heavy-weight castings.

As a general average, all the grades will carry about 3.5 per cent. carbon, in total.

The recent specifications of the American Society for Testing Material require a transverse test on specimens $1\frac{1}{4}$ inches diameter and 12 inches between supports, load in the middle:

2500 pounds or over for light castings.

2900 pounds or over for medium castings.

3300 pounds or over for heavy castings.

with deflection before rupture not less than $\frac{1}{10}$ inch. Tensile strength of the aforesaid grades respectively to be not less than 18,000, 21,000, and 24,000 pounds per square inch of section. While these standards

are valuable in maintaining a high quality of product, yet they may imperfectly represent the resistance of the metals in actual service. We know that cast-iron is in extensive use that falls far short of these requirements. High tensile strength is frequently associated with brittleness, and is not always indicative of superiority.

For heavy machinery, etc., cast-iron is used in heavy masses, through which working stresses are imperfectly distributed, and probably is much softer and weaker in the middle of the mass, where it has cooled slowly, than at outer surfaces, where the metal has more rapidly cooled.

Furthermore, castings are usually under considerable internal strain, due to unequal contraction, and although this internal strain gradually disappears, it may have some disturbing influence after the casting has been put in service. It has been the practice of the writer to assume an ultimate tensile strength of 16,000 pounds per square inch for ordinary iron castings, and to limit working stresses from 2000 to 4000 pounds per square inch, according to the conditions and character of the service.

Cast-iron offers a high resistance to compressive stress, and although this resistance varies within wide limitations, it may be assumed as a working basis to be about six times that of the tensile strength, or say 95,000 pounds per square inch of section.

Cast-iron is imperfectly elastic as compared to the superior forms of the metal. It presents no definable elastic limit, and exhibits marked permanent set, under low loads, either in tension or compression. Experiments continued for several years indicate that when loads exceeding one-half the ultimate are applied, failure eventually ensues. It may therefore be assumed to have a practical elastic limit in tension of about one-half the breaking load.

The coefficient of elasticity is likewise variable, in contradistinction to the constancy of the elasticity, under ordinary conditions, of wrought-iron and steel.

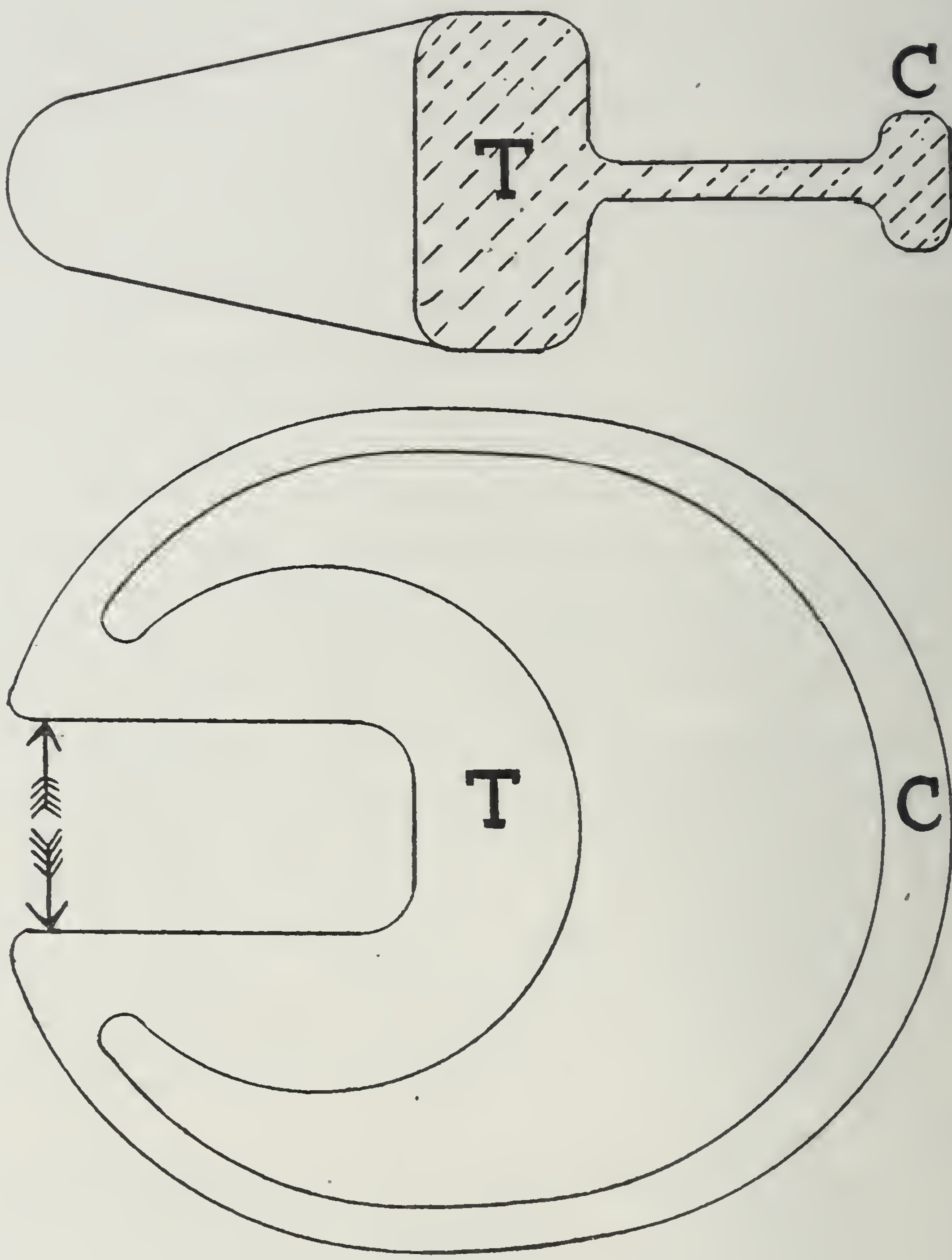
Recorded experiments indicate that the modulus of elasticity varies considerably in extreme cases, and is nearly alike in tension and compression. A modulus of 13,000,000 pounds appears to be a fair valuation for direct tension and compression; or, for bending loads applied transversely, this modulus appears to average 16,000,000 pounds when used in computation with the commonly accepted formula for flexure.

In the middle of the past century as cast-iron became extensively applied to structural purposes, its physical properties were studied

with great care, and the experiments of Hodgkinson and Fairbairn in England, and their contemporaries, yielded a fund of information on the subject. Seeking a section of beam which should exhibit the highest ultimate strength in proportion to area of cross-section, or of the weight of metal employed, Hodgkinson advocated a section in which the tension flange exceeded the compression flange about six to one in sectional area, the web usually tapering in thickness from the tension flange, diminishing toward the other flange. This form of beam was largely adopted, and took precedence as long as cast-iron was used for beams in structures. We find that the same method of reasoning influenced the machine designer in disposing cast-iron to seeming advantage in the construction of machines, massing the metal to resist tension, and permitting high unit stress on metal in compression; and especially is this observed in machines of the open jaw or gap type, such as presses, punching and shearing machines, etc. The writer believes that usually the unit stresses should be little, if any, higher in compression than in tension, for the following reasons: In machinery rigidity or stiffness is usually the chief consideration; many machines do not fulfil the intended purpose properly, not by failure through fracture, but by a want of sufficient stiffness. Deflection has to be limited, and when that is done, breaking from excessive tension is sufficiently guarded. Remembering that cast-iron yields to compression, as much as with the same unit stresses it yields to tension, it follows that the compressive stress should not exceed the tensile strength per unit of section if it is desired to dispose a given mass of metal with least deflection. It is believed that rupture sometimes occurs in a machine apparently through tension, where the origin of the weakness could be traced to a want of material to sufficiently resist compression, the improperly supported tension side severing by cross-bending or transverse stress.

Taking for illustration an open gap machine with frame as illustrated on page 310, tension at T and compression at C, if the section is so shaped that compressive unit stress is six times that of the tensile unit stress, then, elastic moduli being equal, the frame will yield at C six times as much by compression as it does by tension at T. This permits an oscillation of the mass at T around its center. If this oscillation becomes dangerous, by extent or frequency, the frame will break by cross-bending at the mass T, giving the impression that more material is needed to resist tension, whereas the fact may be that more material should be placed at C to prevent excessive yield by compression.

Owing to the peculiar physical characteristics of cast-iron, it has not been found practicable to harmonize experiments with the theory of flexure. Many reasons are offered for this, and modifications of the usual accepted theory have been propounded which will not be discussed here. It has been found necessary to introduce into the equa-



tions moduli or coefficients which have no apparent relation to the direct strength of the metal, and which vary widely for different dimensions and shapes of cross-sections. As the cross-sections under consideration are frequently of unsymmetrical and irregular shape, the computation of flexural moments is tedious and frequently useless if the computer has not a correct modulus to apply to satisfy the conditions

of the section under consideration. It is therefore desirable for the designer to keep a record of experiments, and of failure of castings under known loadings, and from these results derive coefficients, by means of which the strength and stiffness of various sections can be approximately known without recourse to the usual calculation for the resisting moments of the section.

For convenience in practice the writer has in past years collected considerable data on this subject, which he will endeavor to submit hereafter.

In machinery the working stresses are usually impulsively or suddenly applied, sometimes with actual percussion or impact, and frequently alternate stresses of equal intensity in opposite directions occur in rapid reciprocation. As it is known that a load so rapidly applied as to permit the unimpeded effect of gravity will produce a deflection double that due to the static effect of the same load, it can be seen that the total amplitude of vibration due to rapidly alternating loads must be very considerable. To prevent excessive vibration, the structure should be designed with a limitation of deflection in view, and the amount of this limitation is derived solely from experience, and should be governed largely by the nature of the service to which the material will be applied. For machinery under ordinary circumstances we might assume, in order to obtain satisfactory stiffness, that the deflection should not exceed $\frac{1}{2500}$th part of the span, and under certain conditions, should be much less than this. Indeed, it is quite probable that a deflection in direct proportion to length is not advisable, but that the ratio of deflection to length should decrease as length is increased. For long members in compression, the sectional area must be augmented as the ratio of length to cross-section increases, but for members under variable tension alone, the section should be increased also, or the stress per unit of cross-section reduced, as the ratio of length to cross-sections increases, for the purpose of reducing vibration due to successive extensions. When rapidly alternating stresses occur, it is acknowledged that provision must be made for something more than the greatest stress in one direction alone. There are still differences of opinion and practice on this subject among bridge designers; some maintaining that when the alternations are of slow recurrence, so as to permit actual rest between reversals, no special increase of section is required; others specify that the sum of the sections required for the stresses in opposite directions should be used to suit the conditions. There can be little doubt that the latter estimate is little enough for

machinery when the oscillation of the forces occurs with great rapidity, and especially when the metal under consideration is cast-iron, with a modulus of elasticity about one-half that of steel or wrought-iron. It is a safe general rule for ordinary cast-iron in machine structures to limit tensile stress to 4000 pounds per square inch of section, under the most favorable circumstances; to 3000 pounds when loads are suddenly applied, and to 2000 pounds when the force alternates in direction; these unit loads to be further limited to suit the ratio of length to section, as required for columns or any members in alternate extension or compression, or for beams or members subjected to alternating transverse stresses, the unit stresses on the material should be limited so that the sum of the deflections in opposite directions will not exceed $\frac{1}{2500}$th part of the span, or such other limitation as, according to the judgment of the designer, will provide sufficient stiffness for the intended purpose.

DISCUSSION.

Emile G. Perrot.—I would like to ask Mr. Christie what method he uses for figuring beams. He mentioned, I think, a ratio of 1 : 6 between compression and tension flanges, but did not give the value he uses for the extreme fiber stress, unless he means that 4,000 pounds is to be used the same as in direct tension.

John C. Trautwine, Jr.—In stating the well-known fact that a load suddenly applied causes a deflection twice as great as it can maintain permanently, and about twice as great as it would cause if applied in very small instalments, Mr. Christie so framed his remark as to give the impression that this was the case only when the force applied was that of gravity. I presume, however, that Mr. Christie did not so intend to limit the application of the principle, which, I think, must apply to forces in any direction and however caused.

James Christie.—We cannot at this time discuss the general question of cast-iron beams. The intention was to direct attention to the thought that when the greatest stiffness with least material is desired, the unit stresses of tension and compression should be equal. Tredgold seems to have realized this and designed cast-iron beams with equal flanges. The temporary deflection caused by a load suddenly applied is due to the acceleration of gravity acting on the mass that produces the deflection. Of course, any other force that acted the same as gravity would produce the same effect.

Paper No. 1040.

SUGGESTIONS FOR OPENING STREETS THROUGH GIRARD COLLEGE GROUNDS.

HENRY LEFFMANN.

Read April 20, 1907.

Edward Gibbon says, "Our sympathy is cold to relation of distant misery," and on this principle, true as to small as well as large affairs, I fear that many will feel but little interest in the questions involved in this communication. To those, however, who reside or have much business in the section to the immediate northwest of Girard College the obstruction is serious and exasperating. Perhaps the conditions are all the more exăsperating when it is recognized that no citizen of Philadelphia was more alert to the importance of opportunities for traffic than Stephen Girard, and if one may make the common, though grotesque, supposition that he should return to earth, no one would be more sorry than himself for the conditions that his bequest has been construed as imposing. Girard was, in some respects, a far-seeing municipal engineer, as well as a far-seeing philanthropist. His utterances and bequests concerning street-improvement correlate and vie in moment and prophetic character with his utterances concerning the care of the orphan poor. He is one of the few who have left money to endow public works of general utility; he is one of the few that have endowed institutions not only for education but for maintenance and training. How much more useful is the bequest for the widening of Delaware Avenue and the maintenance of communications between it and Water Street than the Richard Smith bequest for an eccentric memorial gateway at Fairmount Park! How much more benefit has arisen from the establishment of Girard College than from the establishment of Carnegie libraries!

Notwithstanding Girard's foresight, he unfortunately did not realize that the growth of the city would so soon carry a dense population to the northwest of the grounds he appointed for the College. It must be borne in mind, however, that the selection of the present location was a second thought, and possibly in some senses a hasty one. The plan which he set forth in great detail in his Will, dated February 16, 1830, assigned the college building to the square of ground lying between High (Market) and Chestnut, Eleventh and Twelfth Streets,

and ordered that the building be oriented parallel with those streets. By a codicil, dated June 20, 1831, he substituted the tract of about forty-five acres, then known as Peel Hall, which he had recently purchased, further directing that the details of arrangement and construction should be applied to the new site as to the old.

Nothing definite is said as to the opening of streets through the grounds. In other parts of the Will, Girard expresses emphatically the need of avenues for traffic. He left specifically $500,000 "To lay out, curb, light and have a passage or street on the east part of Philadelphia, fronting the river Delaware, not less than 21 feet wide from Vine to Cedar," "To regulate, widen, pave and curb Water Street," and to provide alleys for more easy communication between Water Street and Front Street. He also included provision for removal of frame buildings from within the city limits.

At the time this will was drawn the term "city" referred only to the district from Vine to Cedar (South Street) and from the Delaware to the Schuylkill. The remainder of the county comprehended about two dozen independent centers of population, some established as "districts," others as "boroughs," and the remainder as "townships" or unincorporated "districts." The scheme of a greater Philadelphia had been already foreshadowed, but vaguely, and doubtless no one seriously considered either the consolidation of the whole county into a city or the great extension of purely municipal life to the then remote region of Peel Hall "on Ridge Road in Penn Township."

The great charity was not immediately available. Apart from the unavoidable delays involved in the probate of the Will, distribution of the numerous personal bequests, and settlement of the accounts, the engineering and architectural problems required much time. An additional delay of much moment was due to litigation. Disgruntled heirs made strenuous efforts against the Will, and it became necessary for the city to employ able counsel and carry the suit to the final tribunal, the United States Supreme Court. Girard died in December, 1831, but the decision of the court of last resort was not given until 1844, and the first students were not received until 1848. It was, therefore, seventeen years after the death of the founder that the benefits of his charity began to be felt.

In constructing the building and surroundings the trustees have followed some of the provisions of the Will and ignored others. He directed that the ground should be enclosed by a stone wall not less than fourteen inches thick, ten feet high, capped with marble and

"guarded with irons on the top so as to prevent persons getting over." The last direction has been ignored, as has also a provision that the buildings should be constructed "avoiding needless ornament." That the Corinthian building on the grounds is beautiful I think no one will deny, but I would be astonished to hear any one claim that it is in accordance with the above phrase.

The inconvenience of the Girard College grounds and the unsightliness of the jail-like stone wall began to be sources of vexation within a score of years after the death of the founder, and the vexation has been growing worse each year. The section of the city that is cut off from free communication is one now densely populated, mostly with the best class of citizens. They are among the most active patrons of the higher class of amusements in the center of the city. The territory is not given over to tradesmen who keep in their shops or to factory hands who live near their work, but the men are in large part engaged in business in the city proper and the women are patrons of the large department stores. Girard College is largely responsible for the fact that between Seventeenth and Twenty-ninth Streets no car-line is available for a continuous journey from Columbia Avenue to points south of Chestnut Street. The grounds block over five squares from east to west; the north and south boundaries, oblique, to the street lines, block nearly three squares from north to south.

I do not intend to enter into a discussion as to the legality of the opening of streets through the College grounds, or the legality of the plans that I propose to discuss for practically abandoning the present site. Such matters must be left to those learned in that maze of word-manipulation and hair-splitting, modern law. The important point is that many thousands of people are deprived of comfort and convenience by an antiquated system, the overturning of which can be easily arranged so as to work no injustice to the obstructor. Under such a condition, the maxim "*salus populi suprema lex esto*" will find proper application and the courts will soon find the road to realization.

Let me now direct your attention to some details of the grounds and their vicinity. The enclosed space is practically rhomboidal, the longer axis at right angles to Ridge Avenue. It includes a little over forty-five acres of nearly level ground. The annexed map (Fig. 1) shows the interference by want of alignment with most of the streets, and also shows that the original buildings, those in the northeast part of the area, were aligned and oriented with the streets and offered no serious obstacle to opening of the latter, while the later buildings are placed so as to consti-

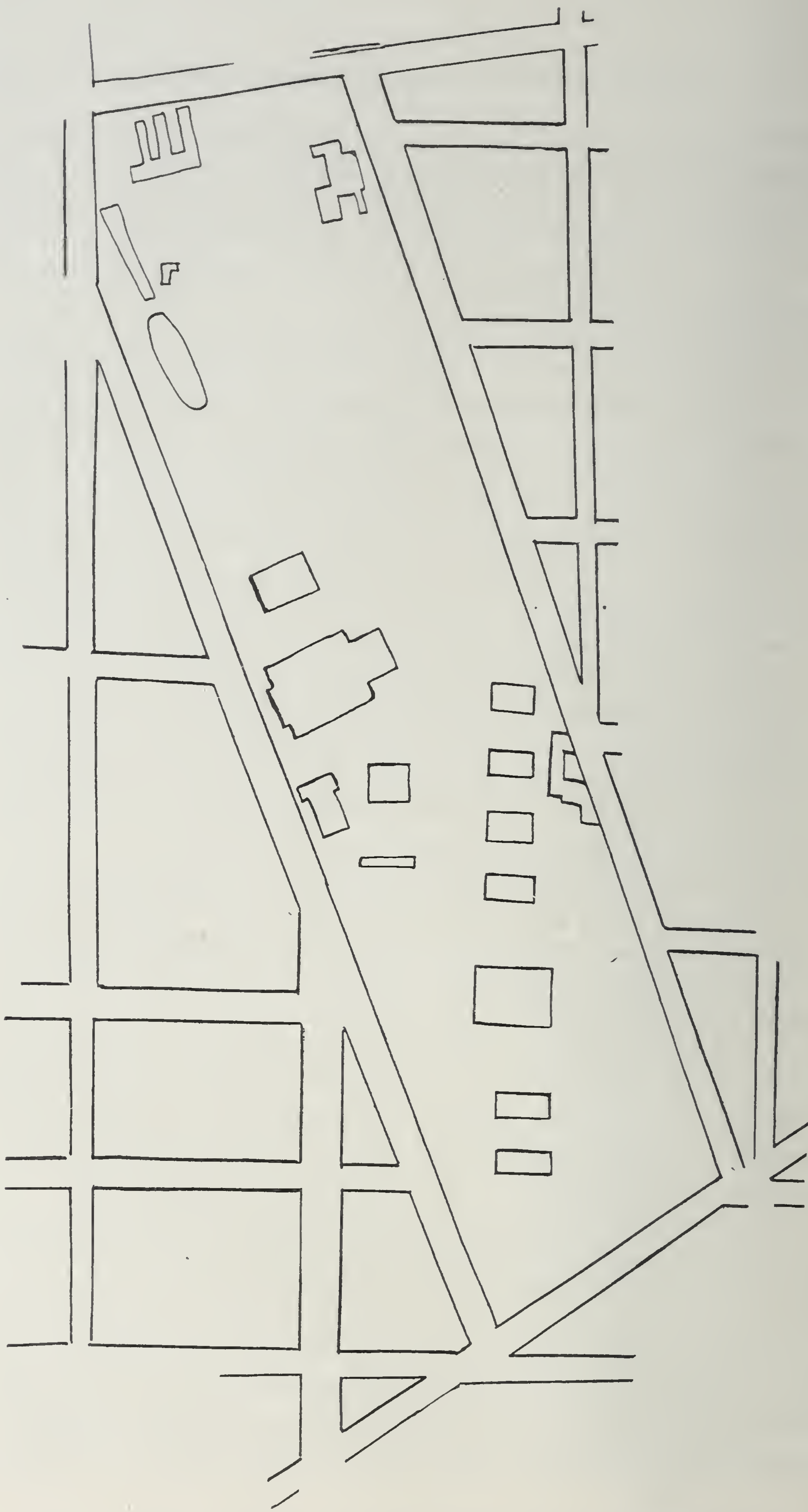


FIG. 1.—GENERAL PLAN OF GIRARD COLLEGE GROUNDS AND VICINITY.

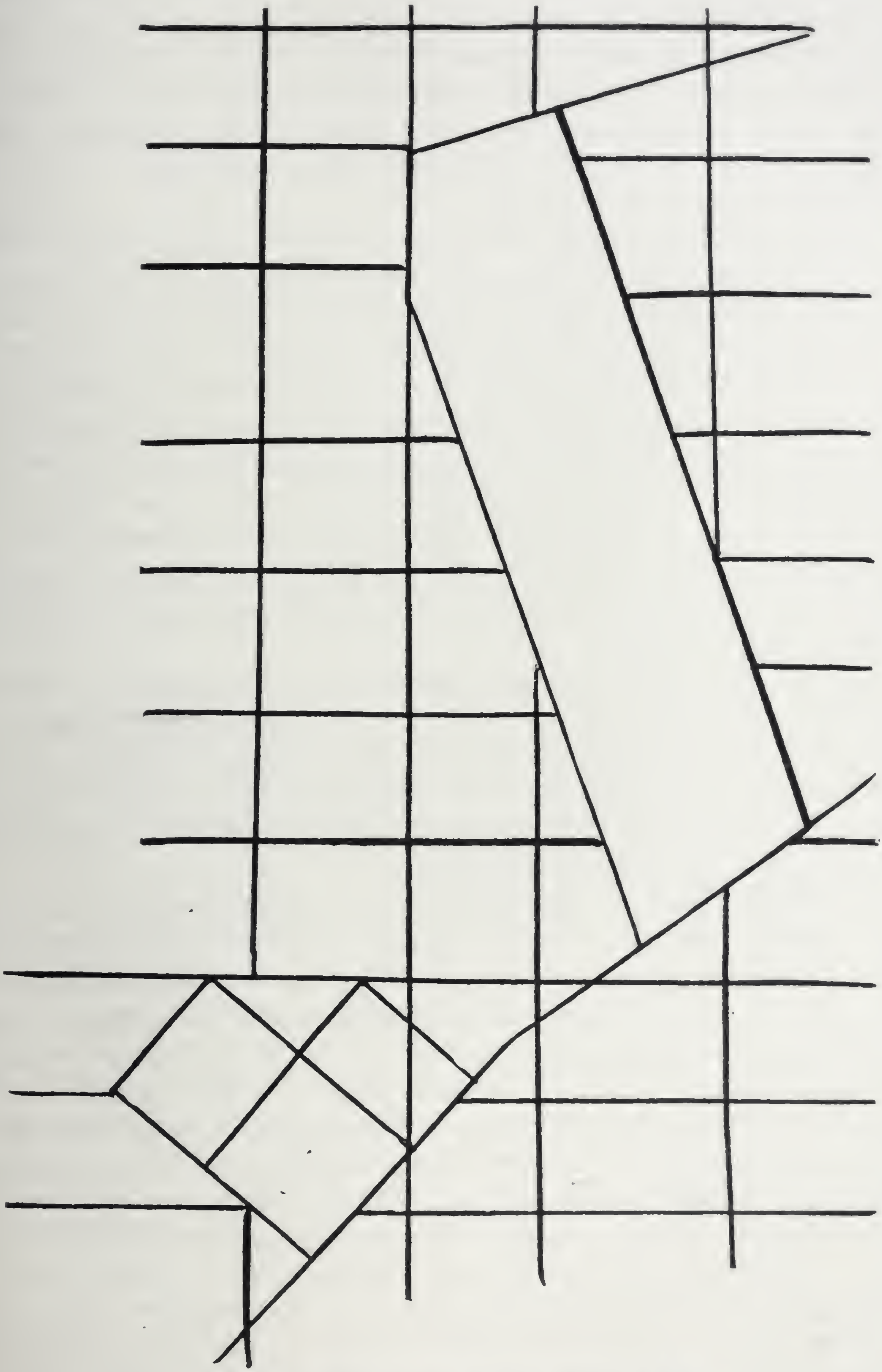


Fig. 2.—Vicinity of Girard College.

tute most serious obstructions. Some of these later buildings were begun at a time of active discussion about opening the streets, and it was thought by many persons, apparently justly, that the locations were chosen especially to render such opening more expensive and difficult. The records of the actions of the governing body of the College in the past do not hold out any hope that it will do anything but act as an obstructionist in the future.

The map (Fig. 2), taken from the topographic map of the United States Geological Survey, shows the serious confusion of street lines in several places in the Girard College locality, owing to lack of foresight, or of the exercise of it, on the part of the city authorities. Long after Girard's death, about the time of consolidation of the city and county, when, as a little boy, I played in the neighborhood of Ridge Road and Poplar Street, the district was mostly rural and the important streets could have been kept on the city plan. This was not done, and it will be seen that the interferences extend from Seventeenth Street to Twenty-fifth Street, and from Brown Street to Thompson Street, part of this being due to the old Francisville lines, and part to the Girard College grounds.

It has been stated in the newspapers that the interrupted portions of Seventeenth and Eighteenth Streets have been placed on the city plan. It is to be hoped that this is true. No legal difficulty will be encountered in opening them and eliminating the annoying detours now necessary. The improvement is a mere question of damages. The city's power cannot be contested.

The Girard College interference is more serious, both as to extent and technical difficulty. I have pointed out above that, contrary to general impression, Girard did not declare in his Will that streets were never to be opened through the grounds. It seems to me, indeed, that such a declaration should not be valid. The necessities of the community at large are paramount to private interests, and still more so to personal feelings. It does not seem reasonable that any person should create a permanent limitation in the adaptation of the land-areas of a city. All such arrangements should be subject to revocation at the desire of the majority, properly ascertained. As a minimum relief, the opening of Twenty-third Street may be suggested. This is about midway on the line of obstruction. It seems feasible to open it without serious interference with the use of the grounds. The street would not be used much for heavy traffic, as very little of such follows that line. The principal traffic would be foot-

passengers and street-cars. The grade might, therefore, be made so as to sink the roadway below the present surface level, and by raising the surface somewhat for a short distance on either side, the road could be concealed by hedges, bridges being provided in one or two places for communication between the two parts of the grounds. To enable the grade to be still further reduced, the road might be curved as indicated in Fig. 2. Fourteen feet might be allowed for the clear space under the bridges. These could be raised about three feet, so that the net depth of the covert-way would be only eleven feet, which in a distance of 800 feet, secured by curving the roadway, would give an average grade of less than three per cent. The opening of Twenty-fourth Street might be still easier, but this plan would leave five squares interrupted.

On examining these conditions, it will be seen that the time has come to make radical changes in the grounds as well as in the methods of education and training. When Girard wrote out the details of the bequest, the locality which he selected was rural, the revenues from endowments were less than at present, and even he, with his municipal foresight, did not realize how the College might be surrounded with a dense city, nor how varied and extensive the lines of education would become. Mechanic arts, agriculture, forestry, and pedagogy have become prominent avocations for wage-earners. The changes that have occurred since the bequest was drawn are indicated by the restriction of the benefits to "white male orphans." In this section of the country such a restriction is unusual. The common phrase for charitable endowments is that the benefits are to be extended without distinction of race, color, creed, or nationality. Girard lived at a time when chattel-slavery was an essential part of our national life. He owned slaves, and was also, probably, not wholly ignorant of the practical phases of the slave trade, for although during most of his active life this was contrary to law, yet it was carried on surreptitiously by many "respectable" citizens down to the period of the Civil War.

It would be a great advantage to the city and to the pupils of Girard College if the institution could be transferred to a point many miles from the city. A tract of land half a mile square some half a hundred miles from Philadelphia could be obtained at a moderate figure. This tract should include some rolling and some bottom land. On this could be established schools for general and manual training; general agriculture, including dairy-farming; horticulture; fruit culture; forestry and landscape gardening. Ample room could be at hand for outdoor sports, including all aquatic exercises. All this would make

possible a much greater variety of training and afford opportunities for a much larger number of boys, for many of the occupations could contribute to revenue. Thus the usefulness of the institution would be increased.

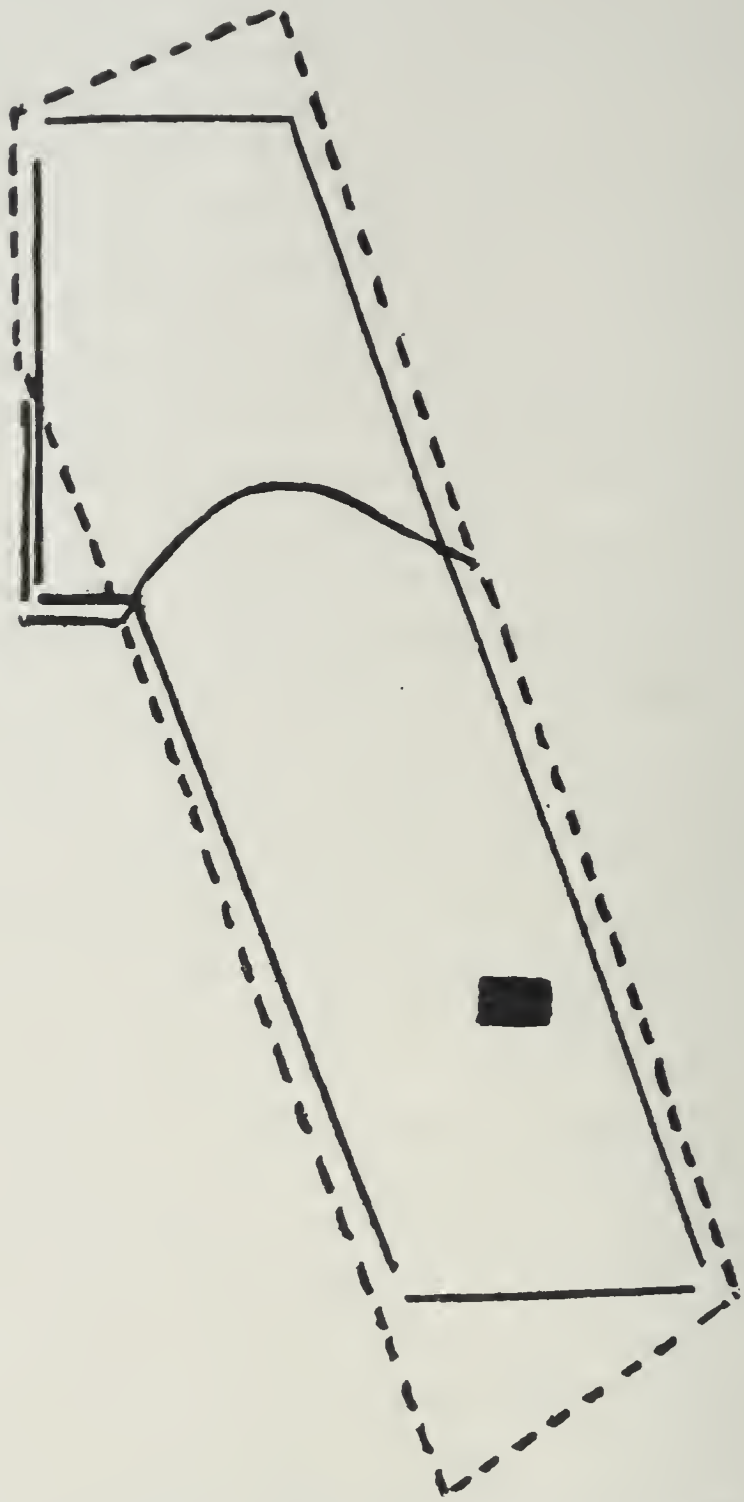


Fig. 3.—Proposed "Stephen Girard Playground."

On the other hand, the present grounds could be laid out as playgrounds. The unsightly walls should be taken down and substituted by a hedge or other ornamental line. All the buildings should be razed, except the main one, which as a beautiful specimen of architecture would be an ornament, and could be utilized as a museum,

art-gallery, and lecture hall. The general area should be opened as a playground, not as a formal park. It is admitted by those who have studied the question of child-life in cities that one of the great needs is ordinary playgrounds. It would be sufficient to open Twenty-third Street by means of the covert-way for general traffic. The extreme eastern and western portions might with advantage be sold for building purposes, Twentieth and Twenty-sixth Streets being made respectively the eastern and western boundaries. These streets might be somewhat widened where they cross the lines of the grounds.

An additional advantage would accrue if the House of Refuge, located to the south of the grounds, could be also abandoned. Just aswith the College, so with the Refuge, both the city and the inmates would be benefited by the substitution of a home in the country.

The map (Fig. 3) shows the changes suggested. The broken line is the present boundary of the Girard College grounds; the double line, unbroken except at a few points, to indicate entrances, shows the boundaries of the proposed playground, which might be called with great appropriateness "Stephen Girard Playground."

DISCUSSION.

J. Kay Little.—What was the date of the original building? I would also like to know if the streets were laid out at the time the buildings were built.

James Christie.—It would mutually benefit both Girard College and the streets of its vicinity if the College was removed to the suburbs or the adjacent country, where it could have sufficient land to conduct agriculture as one of its branches of training and study. This community should, and doubtless would, make ample contributions toward the cost of such an undertaking, in view of the obstruction offered by the College to highway connections, and in consideration of the ultimate interests of this worthy institution.

Paper No. 1041.

NOTES ON THE USE OF PRODUCER GAS FOR POWER PURPOSES.

J. R. BIBBINS.

Read May 4, 1907.

In the admitted breadth of this subject, the author finds the opportunity to direct your attention to certain phases of power gas work that seem to be especially pertinent at the present time. No attempt is made at continuity of thought between the several topics treated, but, instead, the paper presents for your consideration a few more or less closely related points that seem to be of some importance in the present state of the art. One avowed purpose is to emphasize the possibilities of the non-bituminous producers, which, it is believed, has not received the attention it deserves. Particularly is this true of the small isolated plant, which would doubtless be widely adopted were its merits more generally known. The large central station of 20,000 to 50,000 kw. capacity is a matter of more or less gradual evolution, but the isolated plant is entirely one of the present. In cities and other manufacturing centers the power question involves only steam, gas, or purchased electric power. Where natural gas is available, steam is practically "out of the running," and even without natural gas, manufactured gas often forms the most attractive fuel in spite of its high cost; witness your own city pumping station and the novel little plant operated by the Boston "Herald." Now, a careful study of the subject soon develops the fact that producer gas is an important factor. The popular opinion exists that it cannot compete at all with natural gas, but this is by no means universally true.

Limits of Competition with Other Gases.—The best means of analyzing the problem is to consider a definite equipment—for sake of simplicity, a non-bituminous plant as compared with one using natural or manufactured gas. Assume two 500 h.p. plants. As the engine equipments are identical, their operating cost may be left out of consideration. There remains to be determined, for the two cases, the relative cost of gas delivered to the engines. This includes, in the case of producer gas, both operating and capital charges on the producer house proper; *i. e.*, fuel, labor, interest, and depreciation. Assume, further, coal at 12,000 B.t.u. per pound, natural gas at 1000 B.t.u. per cubic foot, manufactured gas at 575 B.t.u. per cubic foot, engine efficiency at

11,000 B.t.u. per b.h.p. hour (full load), generator efficiency at 92 per cent., total producer efficiency at 65 per cent., and one spare (250 h.p.) producer for twenty-four-hour service. Taking all these quantities into proper consideration, the result may be best presented graphically. Fig. 1 shows the *total* cost of motive fluid as delivered to the engines at

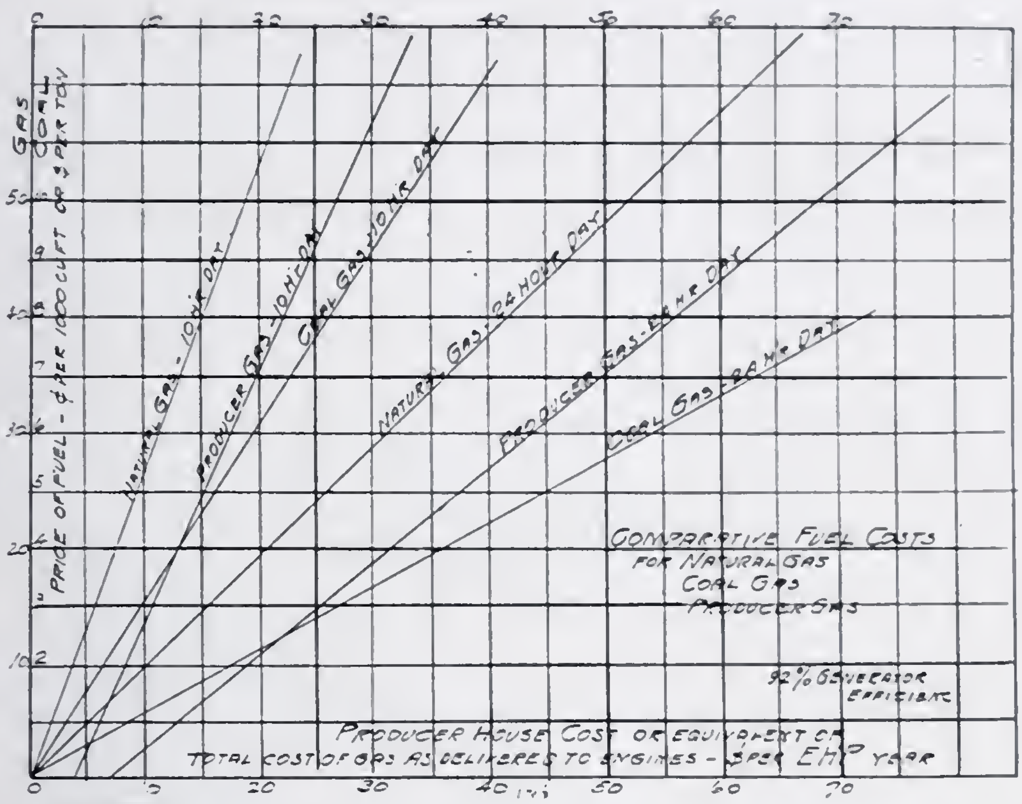


FIG. 1.—COMPARATIVE FUEL COSTS—PRICE TO DOLLARS E. H. P.

various fuel prices. This cost is expressed in dollars per e.h.p. year for convenient comparison with purchased electric power.

Thus:

	10-hour day.	24-hour day.
25c. natural gas =	$9.50 power	$26.00 power.
$2.50 prod. coal =	9.50 "	22.50 "
40c. coal gas =	26.00 "	72.50 "

In other words, for the short day's run, producer gas made from $2.50 coal can just compete with natural gas at 25 cents per M., but it is considerably cheaper in the long run. This equalization of cost has been carried out for the entire schedule in Fig. 2; *i. e.*, the price we can afford to pay for producer coal, in order to compete on an even basis with any price of gas, is shown on the horizontal scale.

Thus:

	10-hour Power.	24-hour Power.
10c. natural gas =	$0.55 coal	$1.05 coal.
15c. " " =	1.25 "	1.85 "
20c. " " =	1.90 "	2.65 "
25c. " " =	2.50 "	3.40 "

This diagram serves to bring out clearly two points: First, that even in natural gas districts there is a legitimate field for the producer where small size anthracite can be had below $3.50; and, second, that for power work, the cost of coal gas is practically prohibitive compared with producer gas. As the manufacturing cost is seldom below 40 cents per M., even a gas-works could afford producer auxiliaries. The use of coal gas is, of course, of little moment in large plants, but in small city isolated plants, it is often given consideration. These charts incidentally furnish a direct comparison between the cost of motive fluid delivered in the form of heat and in the form of electricity from water-

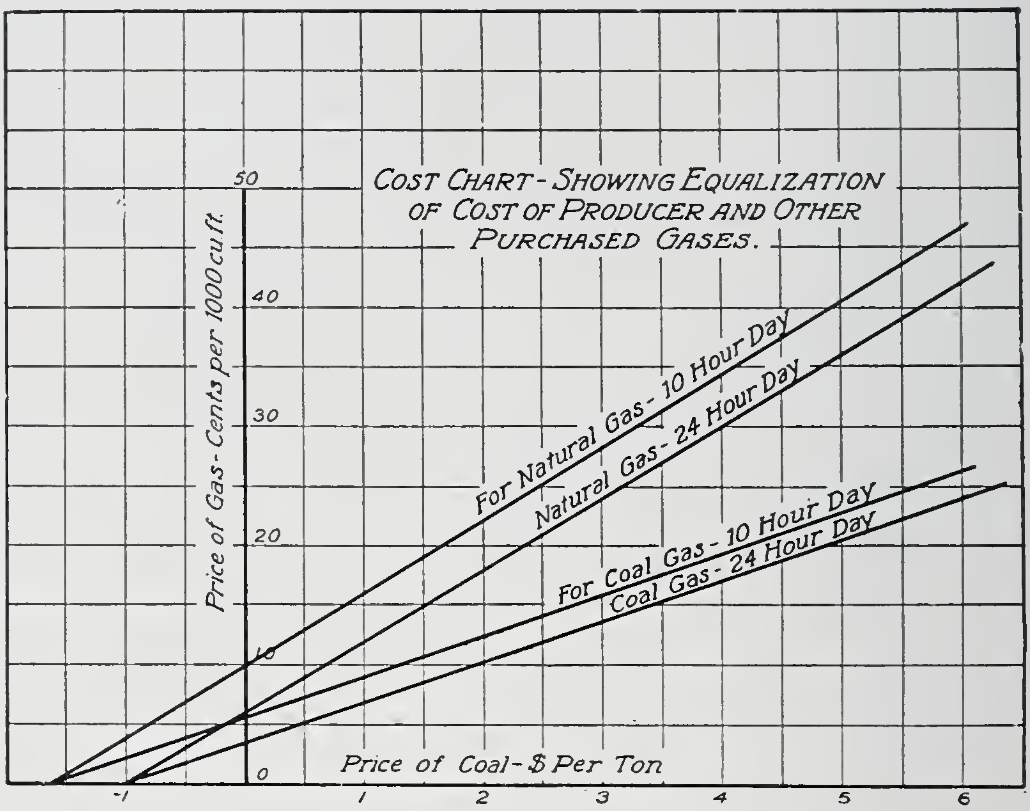


FIG. 2.—COST CHART—PRICE TO FUEL.

power or other plants. Of course, the operating and capital costs of engine and electric motor must be respectively added.

Operating Efficiency of Typical Plants.—There is plenty of evidence that we have not been too sanguine over producer gas operation, and to prove the point, the results from two plants may be cited: one a small anthracite plant of 25 h.p., and the other a 500 h.p. plant operating the works of the Norton Company, Worcester, Mass. This small plant may be regarded as an example of producer gas working under the most favorable operating conditions—fourteen hours daily standby, forty-three and one-half hours over Sundays. The following data summarize a week's run, chosen so as to bring into the average one

starting period from over Sunday, when extra fuel is required to make up for starting losses.

TEST OF 25 H.P. ISOLATED PRODUCER POWER PLANT.
Wilson & Smith, Worcester, Mass.

Date.	Duration of Run.	Coal Used.		Coal b.h.p. Hr.		Remarks.
		Producer.	Boiler.	Producer.	Total.	
7-9-1906	hrs.	lbs.	lbs.	lbs.	lbs.	
Monday.....	$10\frac{1}{2}$	630	184	2.3	3.1	Load approx. constant—25 h.p.
Tuesday.....	"	470	171	1.7	2.4	Plant loading factor (24-hrs.)—34%
Wednesday..	"	315	137	1.2	1.7	Boiler Coal, 29% of total.
Thursday....	"	335	165	1.4	1.9	Coal — Anth. Pea, 13,000 B.t.u. —lb.
Friday......	"	300	140	1.1	1.8	Westinghouse equipment throughout.
Saturday....	$4\frac{1}{2}$	90	80	.8	1.5	
Sunday......	...	...	...	...	...	
Week.......	57	2140	877	1.5	2.1	

You will observe that the average coal consumption for the week, works out $1\frac{1}{2}$ pounds per b.h.p. hour for the producer alone, or 2.1 pounds including the fuel for a small steam boiler used for blowing the producers; also that although the producer, *per se*, showed a fair average efficiency—about 64 per cent.—yet the plant was considerably handicapped by the inefficiency of the small steam boiler necessary. In this regard, it is but justice to the producer art to say that in such small sizes the suction type is far preferable to the pressure, and it is certain that even a higher producer efficiency could be obtained. The test is presented simply to show the possibilities of producer work.

The Norton plant contains a Westinghouse horizontal tandem double-acting gas engine unit, and a single battery of Loomis-Pettibone bituminous producers, with the necessary auxiliary equipment. The fuel used is Pocahontas slack, which runs about 14,000 B.t.u. per pound. Under normal conditions, the plant operates ten hours per day (fifty-five hours per week), exclusive of Sundays. During the shut-down on Sunday, the producer is cleaned out, new fires built, and scrubbers and boiler also cleaned, if required. The load is fairly steady, averaging 75 per cent. of the plant capacity, with 30 per cent. total fluctuation.

OPERATING RESULTS OF 500 H.P. GAS POWER PLANT.
Norton Emery Wheel Co., Worcester, Mass.

Number of weeks run	Seven.
Average hours per week	Fifty-three hours.
Weekly output	12,464 kw. hours.
Average loading factor of plant	21.9%
Average loading factor of engine	78.7%
Coal used	Pocahontas slack.
" gasified in producer per week	23,441 lbs.
" for building fires per week	2,376 "
Total coal used per week	25,817 "
Percentage auxiliary coal	10.14

	Kw.hr.	*B.h.p. hour.*
Coal per unit in producer	1.88 lbs.	1.29 lbs.
Total coal per unit	2.07 "	1.42 "
Heat consumption per unit in prod.	26,300 B.t.u.	18,050 B.t.u.
Plant efficiency (producer)	12.96%	14.1%

The above table summarizes a seven weeks' run on the plant under normal conditions. The line headed "Producer Coal" gives the amount of fuel gasified during the regular working day runs, inclusive of fourteen hours standby periods. "Total Coal" includes also the extra fuel used for rebuilding the fires on Sunday, which amounts to over 10 per cent. of the actual producer coal.

These results are striking. With a station load factor of 22 per cent. (corresponding to a little over $\frac{3}{4}$ engine rating), the plant averaged less than $1\frac{1}{2}$ pounds of total coal per b.h.p. hour, or 1.29 pounds exclusive of fuel for new fires. This is equivalent to about 18,000 B.t.u. per b.h.p hour, or a thermal efficiency, from coal pile to engine shaft, of 14 per cent. At full rating, the plant would consume less than $1\frac{1}{4}$ pounds per b.h.p. hour with a thermal efficiency of approximately 15 per cent. For a plant operating only ten hours a day, this may certainly be regarded as excellent duty, and, if nothing further, it gives us the assurance of equal, or still better economy with continuous twenty-four hour operation on both engine and producer plant, which is the condition to be met in central station work. The conditions surrounding the operating of the Norton plant are thoroughly commercial in every respect, and no attempt is made at ultra-scientific methods.

Relative Status of Bituminous and Anthracite Producers.—Throughout a large part of the eastern seaboard States, both hard and soft coal are equally available at prices not widely different, especially when considered on the B.t.u. basis. The question then arises: Does the greater expense and trouble of the bituminous plant pay in the long run? Speaking most conservatively, it is a matter deserving of close attention. To put the question into concrete form, the cost chart,

Fig. 3, has been prepared upon the definite assumptions given below. The cost includes strictly producer house costs, both operating and fixed; *i. e.*, the total cost of the gaseous fuel delivered to the engine.

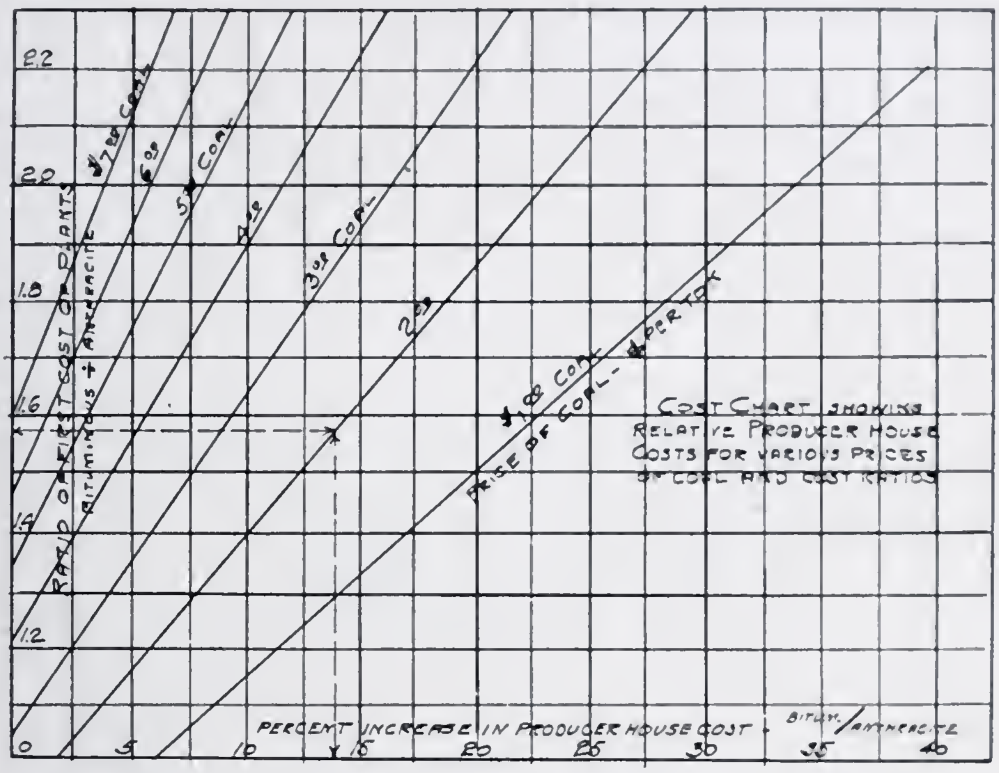


FIG. 3.—PRODUCER COST CHART—RATIO TO PER CENT.

Assumptions.—

Type of Plant.—*Anthracite*—continuous, pressure system.
Bituminous—intermittent, pressure-suction system.
Size.—500-h.p. (rated) plant, full load.
Two 250-h.p. producers—10-hour day.
Three 250-h.p. producers (one spare)—24-hour day.
Engine Room Costs.—Same in both cases.
Base Cost of Plants.—Dollars per h.p. = Anth. $14; Bitum. $22.
Erection.—5% of above base cost in all cases.
Running Repairs.—2.5% of base cost in all cases.
Interest, 5%; *depreciation*, 7.5 %; *taxes*, 1% on variable cost.
Auxiliary Fuel.—Anthracite plant, 15% for boiler.
Bituminous plant, 10% for rebuilding fires.
Producer Efficiency.—(Total)—Anth. 65.2%.
Bitum. 68.2%.
Heat Value of Fuel.—Anth. 13,000 B.t.u.
Bitum. 14,000 B.t.u.
Engine Efficiency.—11,000 B.t.u. per b.h.p. hour.
Coal Consumption.—Anth. = 1.3 lbs. per b.h.p. hour.
Bitum. = 1.15 " " " "
Labor.—*Anth.* = 10-*hr. power*—One prod. man, one ash handler—$4.25 per day.
" 24-*hr. power*—Two prod. men, one ash handler—$6.75 per day.
Bitum.—10-*hr. power*—One prod. man, one helper, two Sunday cleaners—$5 per day.
" 24-*hr. power*—Two producer men, two helpers, two Sunday cleaners—$9.50 per day.

These assumptions are believed to be conservative. They are based on approximate present quotations, and only the strictly fixed charges (interest, depreciation, and taxes) vary with the price of the plant, the other items (erection and running repairs) being held constant on base price. With this precaution, the figures, at other than base price, are not distorted.

This diagram, Fig. 3, shows the relative cost of gas (at a given price of coal) with different cost ratios for these two plants. This is for ten-hour power only. At our base price ratio $\left(1.57 = \frac{\text{Bitum.} = \$22 \text{ per b.h.p.}}{\text{Anth.} \quad = \$14 \text{ per b.h.p.}}\right)$ the total producer house costs, with an average of $2 coal, work out

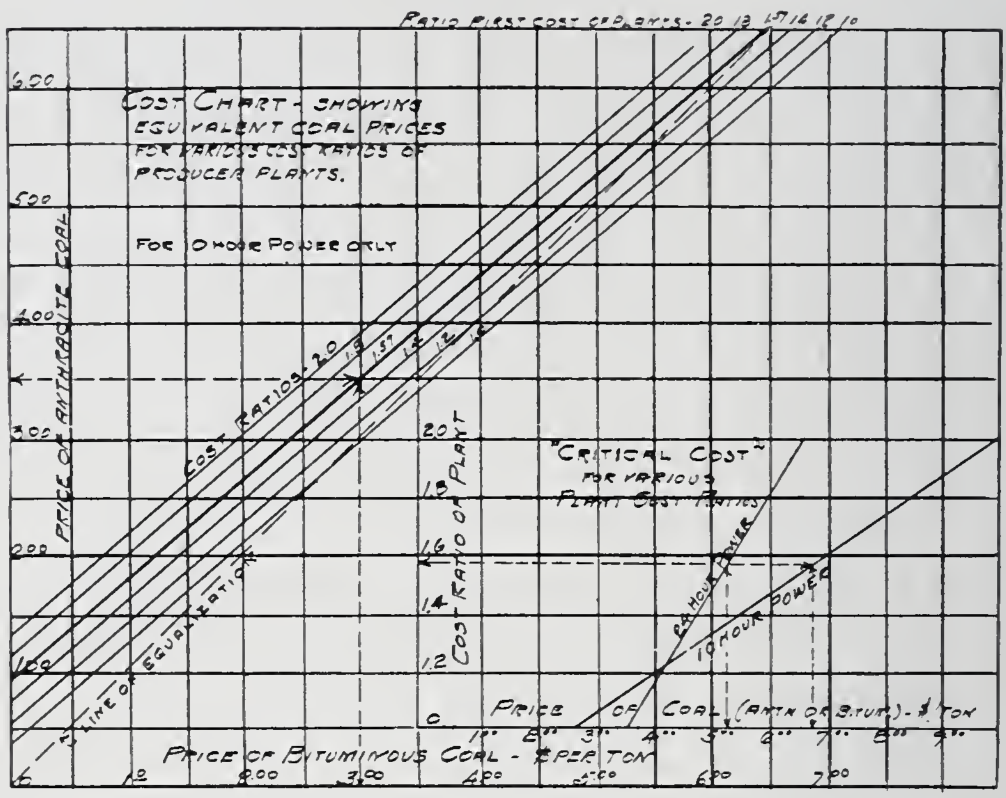


FIG. 4.—CRITICAL COST—PRICE ANTHRACITE TO BITUMINOUS.

about 14 per cent. higher for bituminous than for anthracite plant, in spite of the fact that it has a somewhat higher over-all efficiency. But, as the price of coal increases, the advantage of the anthracite plant decreases, so that bituminous gas would "catch up" at about $6.80 coal.

The converse proposition is shown in Fig. 4, and perhaps brings this out in a clearer manner. The two scales show the relative prices of coal that may be paid in the two plants for the same cost of power, each diagonal representing a definite ratio of first cost. With soft coal at $1.00, we may pay $1.80 for hard coal and still come out "even." Now, as the first cost of the bituminous plant approaches that of the anthra-

cite we observe a decrease in the latter's advantages. Thus, with a first cost ratio of 1 : 1, we may only pay $1.10 for hard coal with soft coal at $1.00; and at $3.00 coal, the situation is reversed—the bituminous plant being cheaper. This point is brought out by the dotted diagonal line sloping at 45° and intersecting at equal intervals the other diagonals. These intersections have the special significance of representing the points of equalization of coal cost; *i. e.*, the critical line above which the anthracite plant has the advantage, and below which, the bituminous plant.

To simplify the diagram, this line of equalization is plotted alone at the right, on Fig. 4, with an additional line for twenty-four hour power. At our original base cost of plant, anthracite yields the lowest power cost up to a price of $6.80 for ten-hour working, and $5.35 for twenty-four hour power. At an equal first cost of plant, we cannot afford to use anthracite costing less than $2.75 per ton for ten-hour working, or $3.60 for twenty-four-hour working; but at a ratio of 2 : 1, anthracite holds good up to $10 coal.

Now, the author desires it to be clearly understood that this argument is not intended to discredit in the least the bituminous plant, whether of the intermittent or continuous type, but rather to bring out the fact that each type of plant has its own particular field. It is possibly true that the demand for a bituminous plant has so completely engaged engineering attention that the possibilities of anthracite working have been for the time being, overlooked.

Producer Fuels.—It is an evident impossibility to outline districts in the country where a certain type of producer may or may not be profitably employed. New mines are not only constantly coming up, but also new methods are being devised for utilizing fuel formerly considered unmarketable. To give an idea of the relative cost of various fuels, the following table has been compiled for a point about equi-distant from anthracite and bituminous fields—Buffalo. The quotations are not recent, but were received simultaneously, so that the averages are relatively correct. Continuing the previous line of reasoning, we may compare bituminous Run-of-mine with a mixture of Buckwheat, Rice, and Barley; both cost the same per ton—$2.23. But from our foregoing chart, Fig. 4, it appears that for equal power cost, $2.25 soft coal is equivalent to hard coal at $2.85, which is even higher than the price of No. 1 Buckwheat at Buffalo—$2.61.

APPROXIMATE AVERAGE PRICES OF PRODUCER FUELS.

	Dollars per Net Ton f.o.b. Destination.				Remarks.
	Pittsburg.	Cleveland.	Buffalo.	Mine.	
		Anthracite.			
Pea	2.88[3]	3.52[2]	3.16[2]		Sept., 1905, quotations from two separate mines and general market.
No. 1 (Buckwht)	2.77	3.39[2]	2.61[2]		
No. 2 (Rice)	2.46	2.24[2]	2.23[2]		
No. 3 (Barley)	1.92	1.97[2]	1.85[2]		
		Bituminous.			
Screened Coal	1.40	1.95	2.25	1.10	Quotations from separate mines. Penna. bituminous coal.
Run-of-mine	1.25[2]	1.83	2.22[2]	1.00	
Slack	.82[2]	1.43	1.75	.60	
Screenings	.90			.60	
		Coke.			
48-hr. Fdy		3.60	2.00		
72-hr. Fdy		3.85	2.25		
Crushed		3.85	2.25		

[2] and [3] refer to the number of quotations averaged.

It is interesting at this point to note the results of experiments that are being made at East Pittsburg on the smaller sizes of anthracite for producer work. No. 1 Buckwheat is, of course, readily marketable; Rice and Barley, however (and Bird's-eye, as the still smaller size is sometimes called), are restricted by the difficulties encountered in efficient steam raising. Consequently, enormous quantities of these smaller sizes are already available at all old mines in stock banks containing hundreds of thousands of tons of good washed coal at a value of about 50 cents per ton. The final waste product (culm) is also available in even greater quantities at practically no cost. Our experiments covered all these sizes in various mixtures, and thus far indicate that, excepting culm, this low-grade fuel can be used successfully and with fair efficiency in our standard producer with proper care and control of the fuel bed. The samples tested were not even as good coal as usual; the Rice and Barley mixtures averaged as high as 23 per cent. ash, and, moreover, were taken from an old bank that had weathered for nearly twenty years.

A valuable point brought out in the tests is that a mixture of sizes yields good results. This is quite contrary to steam practice, in which the mixing of large and small sizes is generally condemned. In the producer, a mixture of No. 1 Buckwheat, Rice, and Barley, just as it comes from the breaker, proved entirely successful, and almost as easy to handle as if the two smaller sizes were absent. Finally, a mixture of Barley and Rice (in about equal proportions) gives every promise of

success, although this has not yet reached a conclusive test. It makes good gas,— averaging 115 B.t.u.,— and does not clinker, owing to the presence of steam. The smaller sizes naturally show a greater tendency to "pack" than the larger, but this is easily overcome by a thinner fuel bed and a slightly higher blast pressure to overcome the increased resistance. It so seems well to keep the fuel bed loose at the walls, and exercise some care in removing ash uniformly around the producer. Both these precautions prevent "slips" in the bed, which, even if not serious, are sometimes inconvenient.

In marketing the small anthracite, there seems to be an unfortunate lack of uniformity in sizing, which is often the cause of much confusion; not infrequently No. 2 Buckwheat from one mine is practically the same as No. 1 from another. Several factors combine to bring this about— the shape of the screen hole, length of time the screen has been in service, speed of screen, tilt, etc., and, finally, the screen sizes. In his classic study of the waste fuel situation, Mr. Coxe cited sixty-four different screen specifications used by various operators for Nos. 1, 2, and 3 Buckwheat and culm. These varied from 30 to 100 per cent. in diameter for supposedly the same size coal. In spite of the later improvements toward uniform sizing standards, we find it necessary to specify a test for dirt; viz., a maximum of 5 per cent. passed through a $\frac{1}{16}$-inch mesh screen.

Automatic Regulation of Producer Output.—It is the general impression that a gas-holder of considerable capacity is an absolute necessity in a producer plant to insure at the engine a supply of gas of uniform quality and pressure. A holder can, of course, be made use of to advantage; it is a necessity in producer plants of the intermittent type, serving to equalize any irregularities in the quantity and quality of gas produced. On rapidly fluctuating loads it is, of course, impossible, with hand regulation, to follow these fluctuations, and were a holder not interposed between engine and producer, there would be an excess of gas one moment and a deficiency the next. In the intermittent system, where two kinds of gas—viz., water and air gas—are used, a mixing holder is an absolute necessity. Frequently separate holders are used for these two gases, which are then mixed in the proper proportions on their way to the engine.

In a continuous system, however, a holder is not a necessity, provided means are employed to control the production of gas according to the demand from the engines. Such a system has already been worked out in very simple form, and the results obtained are commented

upon in a series of tests made at East Pittsburg a short time ago are noted below. In principle, the apparatus embodies the following parts:

(1) A small pressure regulator of the diaphragm or the gasometer type, the interior communicating by piping to the gas main from which the engines draw their supply.

(2) A steam blower of the ejector type, supplying steam and air to the producer in the required proportions.

(3) A small throttle valve in the steam line to this blower connected by lever to the moving element of the regulator.

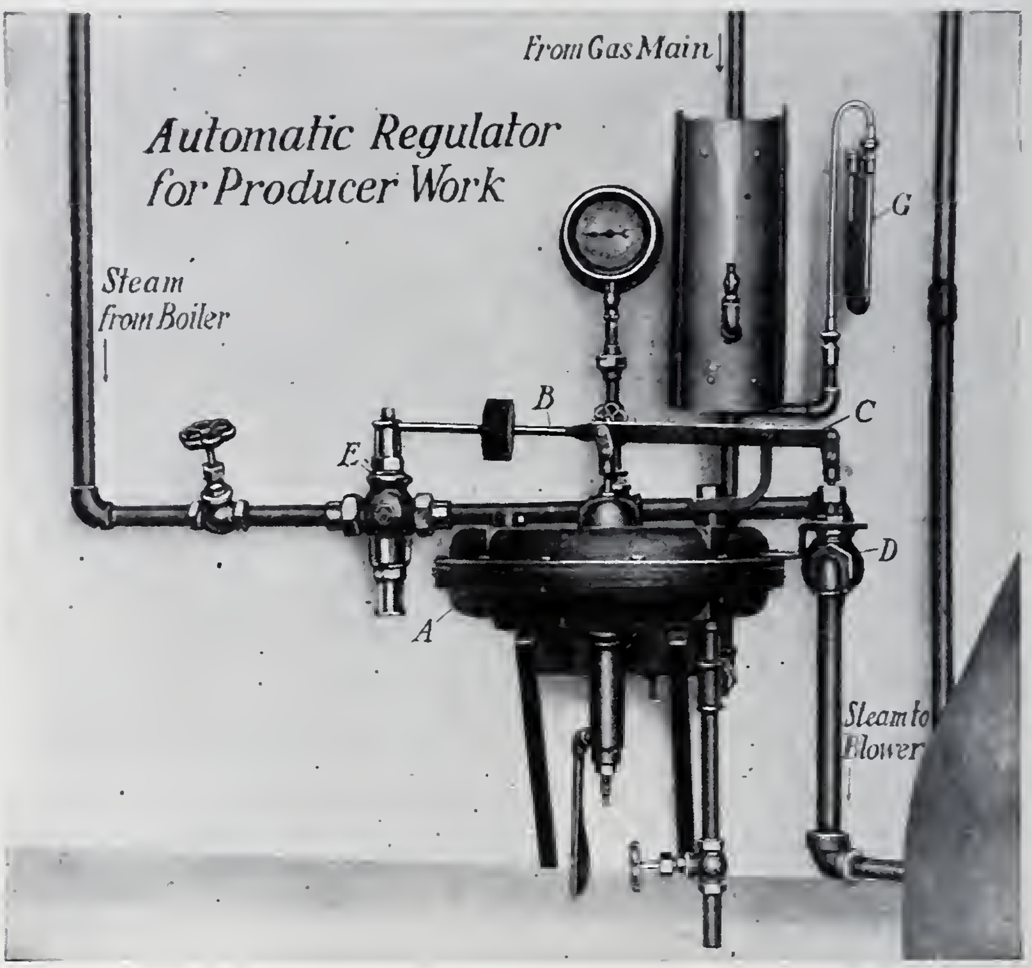


Fig. 5.—Regulator.

Such an apparatus (of the diaphragm type) is shown in Fig. 5. The movable diaphragm contained in the split casing (A) connects by lever (B)—fulcrum at (C)—to throttle valve (D). A pressure-reducing valve (E) enables high pressure steam to be used, if desired. A pipe connects the under side of the regulator with the gas main. The tell-tale flame gives a continuous indication of the character of the gas made, and gage (G) shows the pressure on the gas main at all times. It is evident that a change in pressure in the main, due to greater or less demand from the engine for gas, will cause a movement of the diaphragm, and at the same time a corresponding change in the pressure

of steam delivered to the producer blower. On the other hand, the output of gas from the producer is entirely dependent upon the pressure of steam at the blower. The general result is that regulator and producer respond almost instantaneously to fluctuations in the pressure of and demand for gas. This system of regulation is so sensitive that the output of the producer may be varied from zero to maximum in a period of one or two seconds, while maintaining a practically constant pressure delivery in the gas main.

A test was made on a 500-h.p. continuous type pressure producer burning anthracite coal. In this test the output of gas was varied by closing a by-pass valve from the gas main to atmosphere. As the changes in rate of output were made by spinning this valve by successive turns, it is evident that these changes came as quickly as they could possibly occur in the actual power plant. The regulator was set to deliver gas at about one-inch water pressure. Although it has been in service for many months, it held the pressure within limits of 0.3 to 0.4 of an inch above and below mean, except at points of changing output, where the inertia of the regulator carried the pressure somewhat above and below the stationary pressure. To determine what effect, if any, this method of regulation had upon the heat value of the gas, calorimeter readings were taken every ten minutes showing an average of 133.5 B.t.u. with a total variation of 3.75 per cent. above and below mean. Such a small variation is negligible, and shows that the heat value is quite independent of the rate of gasification.

This regulator governed so closely that engine tests with producer gas have been made at East Pittsburg without the help of the usual pressure regulator in the gas line to the engine. It was at first anticipated that this method might affect the engine when coal was being charged to the producer. At such times the pressure usually fluctuates for an instant, over a range of several inches (water). It was found, however, that the engine did not show the least signs of disturbance due to the momentary dropping of the bell; so the single producer regulator now has entire control of gas supplied to the engine. The net result of this system is not only automatic producer regulation, but the abolition of a cumbersome gas-holder ranging up to 15,000 cubic feet capacity and costing from $160 up, per thousand cubic feet. This reduces the standard producer plant to the simple unit system: generator and scrubber directly connected and self-contained.

Power Plant Arrangement.—The simple manner in which this scheme of plant works out in practice is well illustrated in a station recently

put into operation, serving a large industrial works with light and power generated from anthracite coal. Fig. 6 shows a sectional elevation of the producer plant proper. Note the simplicity and directness of piping, due to the absence of a gas-holder, all of which is above ground and can be readily tested for leaks. This producer equipment is in duplicate throughout, with the exception of the coal elevator and boiler for supplying steam to the producer. The excellent coal-handling arrangement is clearly shown in the section. This drawing also shows the steel-concrete building construction with overhanging tile roof—an excellent form of fire-proof construction for gas power plants.

There is considerable advantage to be derived from an independent

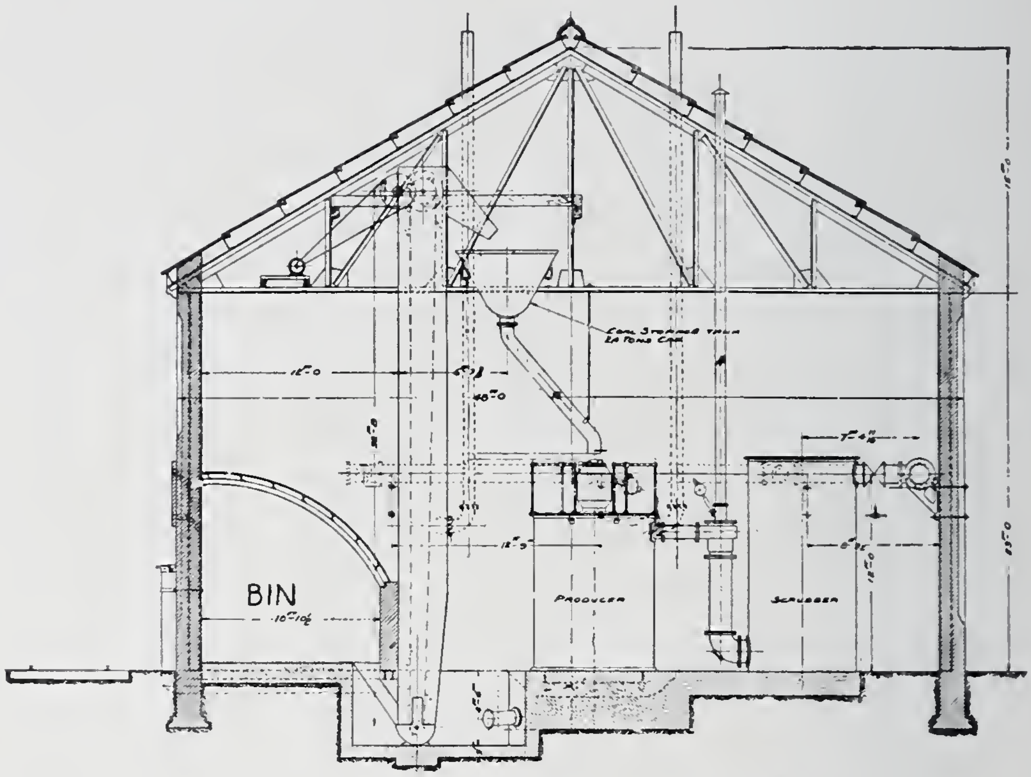


Fig. 6.—Power Plant Section.

scrubber for each producer. This arrangement requires very little more space than with a centralized scrubbing plant, and being on the unit system, does not interfere with repair work when the plant is to be operated continuously. It also avoids a considerable amount of duplicate piping. The producer blowers are brought out into a concrete pit containing also the elevator boot, the whole covered by steel floor plates. This effectively confines what little noise is made by the blowers in action, and at the same time provides easy access to them.

Although with fire-proof construction it is unnecessary to carry insurance upon a producer building, this is sometimes deemed desirable. The restrictions of the underwriters frequently result in a separation

of engine and producer buildings. This unfortunately disturbs, to some extent, the centralization of the work of the power plant operating force; but, on the other hand, results in a lesser building cost. For the producer plant proper, a cheap steel building is often adopted. In England this is carried still further, and practically no building at all is provided for the producers, as in the case of the handsome power station of the Midland Railway terminal at Heysham Harbor. But in America, owing to the more rigorous climate, this is rather out of the question. In the plant of the Gould Coupler Company, at Depew,

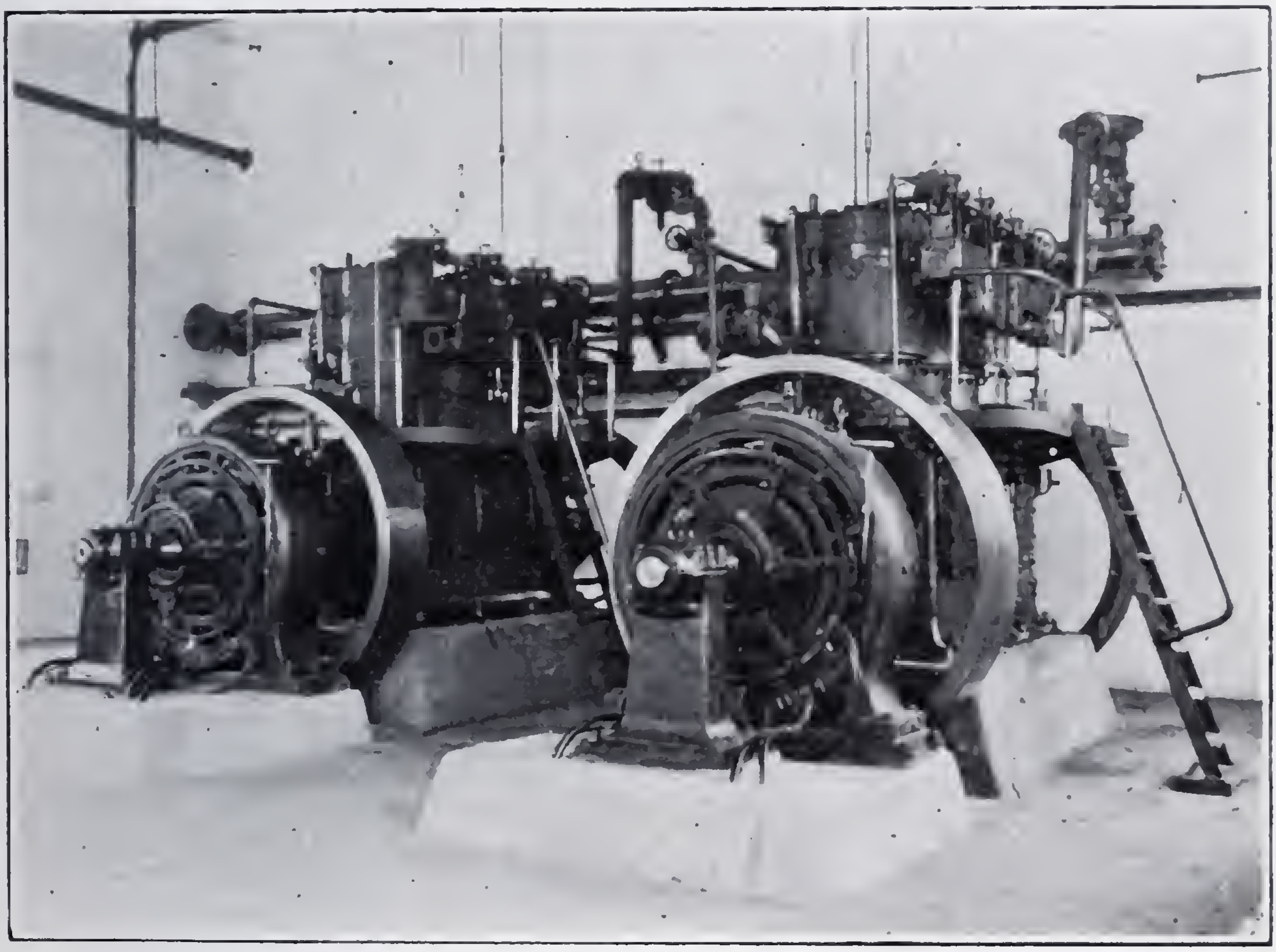


Fig. 7.—Producer Plant Engine Room (see Fig. 6).

N. Y. (paper, A. S. M. E., December meeting, 1906), a compromise has been effected. While the generating equipment is housed in a substantial brick and steel building, the producer equipment, located for local convenience some 500 feet away, is housed in a much cheaper structure having brick walls, corrugated steel roof, concrete floor, and charging floor of boiler steel. In another plant of 400 h.p. capacity, operated by the Citizens' Electric Company, Keene, N. H., both engine and producer equipment are contained in a single building, the latter occupying only about one-third of the floor space which totals 7.6

square feet per h.p., including space for switchboard, transformers, and office.

Coming now to the larger equipment, Fig. 8 shows a proposed layout for an industrial plant using non-bituminous fuel with producers of the type previously mentioned, and horizontal engines of the same size and type as installed at the Norton plant, upon which operating data have already been given. This plant has a maximum capacity of 1537 kw.,

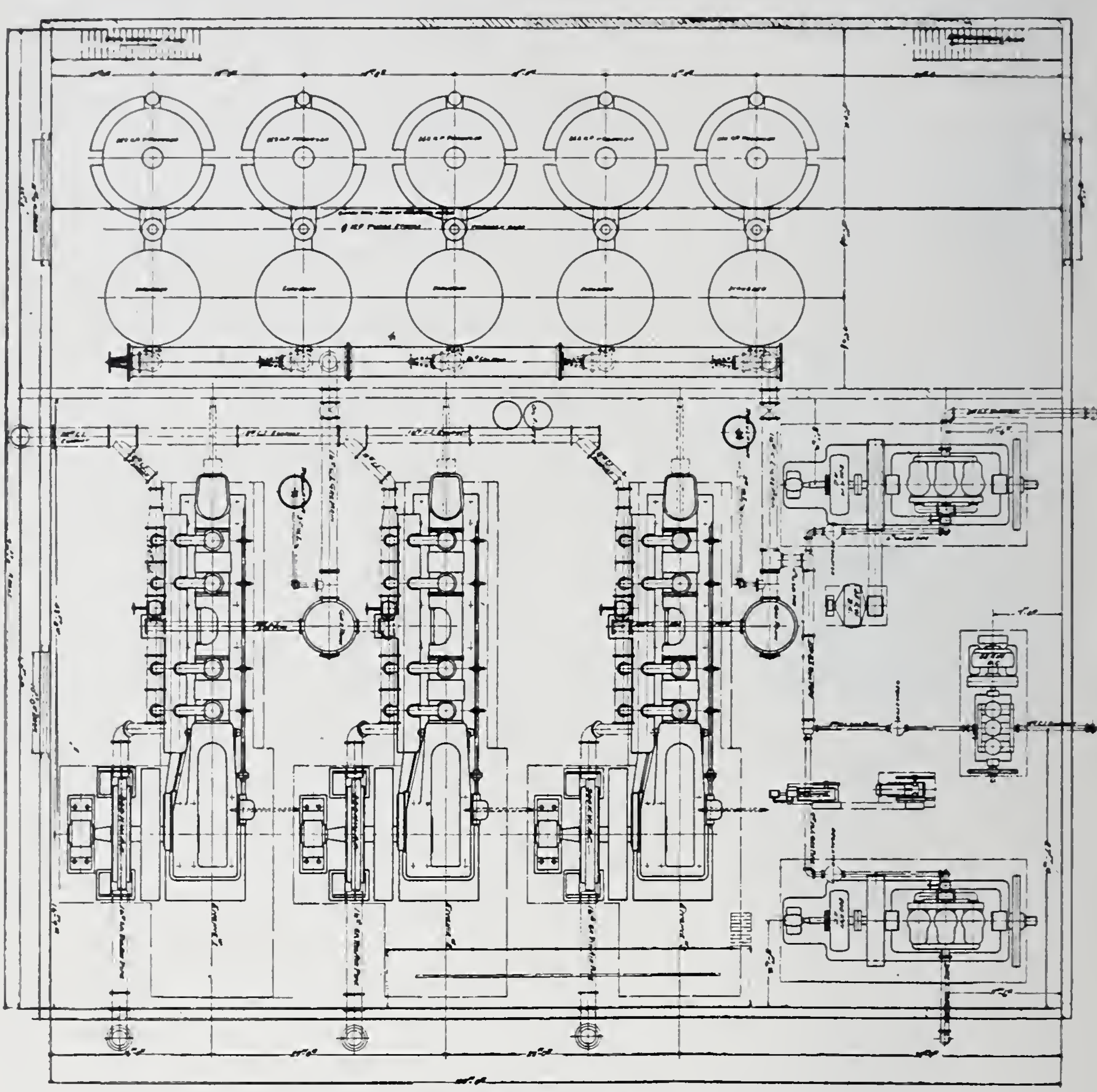


FIG. 8.—POWER PLANT LAYOUT.

which works out to 6.84 square feet per kw., for a plant requiring 10 per cent. overload, or 7.75 square feet per kw. for a plant requiring 25 per cent. overload capacity. For the horizontal units, the limitations of space are fixed by three conditions: First, the space required for the removal of the rear piston; second, the side clearance required for the removal of the cross-shaft; and, third, the front clearance required for the extended foundation necessary to provide sufficient

stability for the unit when installed on insecure substrata. The latter space, however, may be very conveniently utilized for an elevated switchboard. It is very desirable to have the switchboard several feet above the floor level in order that it may be visible from all of the engine throttles. This space is also sometimes used for auxiliaries which are of small size and may be installed in the most convenient location.

The style of unit here shown (tandem, double-acting, single-crank) is generally considered the standard for power plant work, except in cases where specially large units are desired. The twin tandem unit has the advantage of some 5 or 10 per cent. lower cost per kw., and greater compactness, but its over-all efficiency is practically the same as two single tandem units. Unless a plant is of such large capacity that twin tandem units are necessary to reduce the number installed, it is obviously better and safer practice to retain the single tandem units.

This whole question of power plant arrangement involves an exceedingly interesting and profitable study of the relative value of spares; *i. e.*, the amount of excess capacity desirable to meet a given set of operating conditions and its ultimate cost. From the preliminary study which the author has made of this subject, at least one point has become very apparent; viz., that the very large capacity unit is by no means as necessary to secure economic plant operation as is the case in a steam plant. This conclusion is entirely at variance with the popular opinion. Although the subject cannot be gone into in further detail here, it is sufficient to note that not only the price per h.p., but also the heat efficiency of high-grade gas engine generating units are very nearly the same for a 100 or a 1000 h.p. unit.

Operating Results.—That high operating efficiency is not confined entirely to the horizontal type of engine is very evident from the results that have been obtained at the plant of the Gould Coupler Company, preivously mentioned. This plant (equipped with Westinghouse vertical, three-cylinder, single acting engines and Loomis-Pettibone producers) is of only 450 kw. capacity, but shows an average gross coal consumption of about $1\frac{3}{4}$ pounds per kw. hour on a twenty-four hour load averaging about three-fourths of the plant capacity. This is equivalent to between 14 and 15 per cent. thermal efficiency. On an average, the three units are in operation about 97 per cent. of the time, there being no spare capacity in the plant.

There seems to be considerable doubt as to the ability of gas engines to handle alternating current load with generators in multiple. Such

a belief is entirely unfounded. Citing the experience of one builder alone—the Westinghouse Machine Co.: Out of 97,122 h.p. of gas engine operating January 1, 1907, in all parts of the world, fully two-thirds, if not a greater percentage, is in electrical work. At least 50 per cent. of this represents alternating current work, involving parallel operation; and even for 60-cycle work, springs couplings are being dispensed with in the double-acting type engine. Perhaps the best example of what has been accomplished in this line may be found in the gas engine railway station of the Warren and Jamestown Street Railway Co., Warren, Pa. Fig. 9 represents a recording load chart taken from one of the units during its regular operation in parallel with another unit of

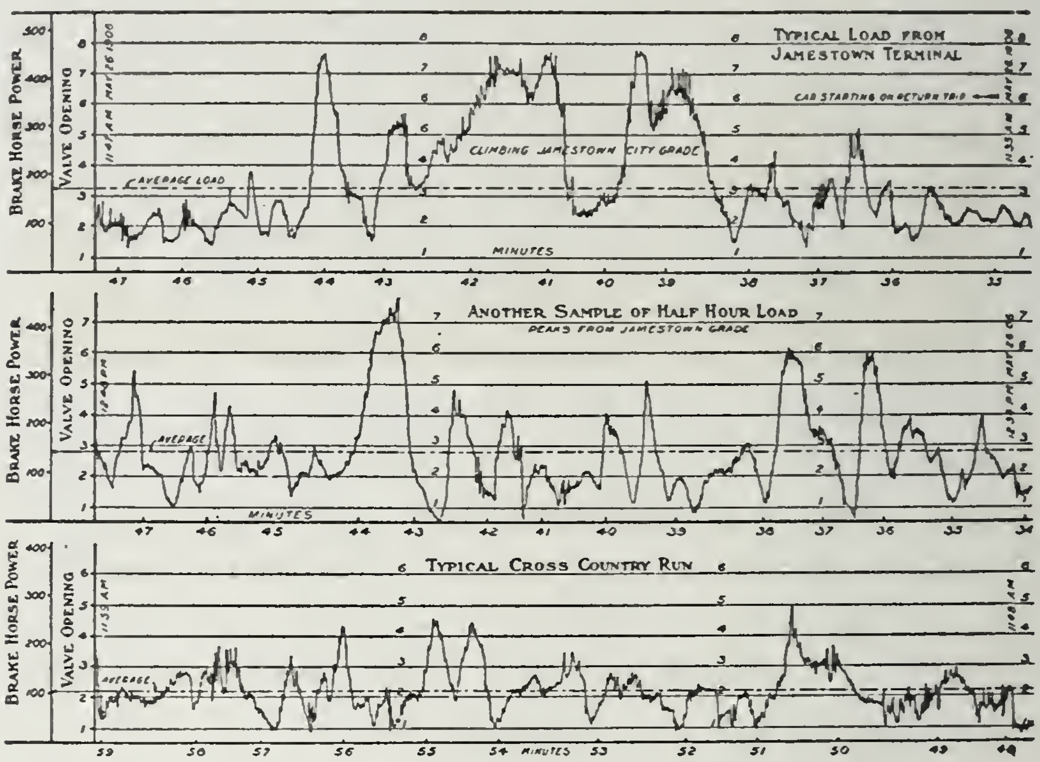


FIG. 9.—WARREN AND JAMESTOWN STREET RAILWAY LOAD CURVE.

smaller size on single-phase, interurban railway load. It is safe to say that a more rigorous test of the regulating ability of a power unit could not be found. The Warren plant has been in continuous operation since the close of the year 1906.

Finally, the results of the thirty-day continuous twenty-four-hour tests upon a blast furnace gas engine at the Edgar Thompson Steel Works, Pittsburg, may be of interest. This engine was operated day and night for an entire month to determine its permanent wearing qualities. During this period (730 hours) the engine was in operation $99\frac{1}{3}$ per cent. of the time, with only two stops, one of which was due to an interruption of the gas supply and the other to a leaky water plunger. Fig. 10 shows a typical twenty-four-hour run—half of which was on

rheostat load and the other half on foundry load. An over-compounded generator accounts for the variation in voltage during the latter period. Continuous records of speed variation taken during these fluctuating loads showed, on an average, a total variation of only four revolutions, corresponding to but $2\frac{2}{3}$ per cent. of total, or $1\frac{1}{3}$ per cent. above and below mean speed. This engine was of the same size and

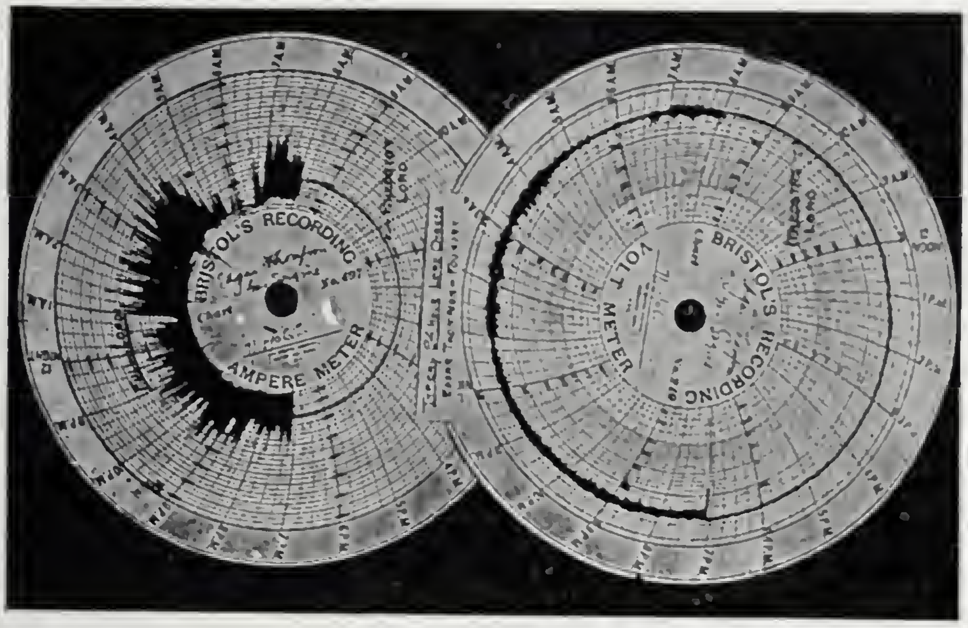


FIG. 10.—CARNEGIE STEEL LOAD CURVE.

type as installed at the Norton and Warren plants, and it is now being replaced by a 1500 kw. twin-tandem unit, also to operate on blast furnace gas. This engine has 54-inch stroke and operates at 75 r.p.m. On natural gas, it is rated at 3100 b.h.p., or 2000 kw. The low heat value of blast furnace gas reduces the rating considerably.

DISCUSSION.

JAMES CHRISTIE.—The use of anthracite or other non-coking coal has heretofore been customary in generating producer gas for power purposes. The abundance and comparative cheapness of natural gas throughout such a large area of the country has prevented any serious endeavor to use bituminous coal for this purpose. It is probable that the near future will witness further development in this respect. The cleaning of gas, rendering it suitable for engine purposes, is essential. For blast furnace gas and producer-gas made from anthracite, the ordinary scrubber, wherein the gas is cleansed through the agency of water, yields satisfactory results. But for producer gas from bituminous coal, tar or soot or both have to be dealt with, and these materials cannot be successfully removed by the ordinary scrubber. In the producer tests at St. Louis under the auspices of the United States Government, the tar was mechanically removed by centrifugal action, and, according to the reports, the operation was satisfactory. Another method, which appears to have come into considerable use in Germany in connection with liquite fuel, is the gasification of the tar by passing the gas

through a secondary body of incandescent fuel. This system has been tried to some extent here with bituminous coal. The removal of the soot or lampblack is a difficult problem, as it mixes very reluctantly with water. Altogether, the use of bituminous coal in the producer for power purposes is still in the experimental stage.

Mr. Bibbins.—Mr. Christie has brought out one of the most difficult problems in producer gas work—the question of cleaning; *i. e.*, getting rid of the tar and lampblack. The Loomis-Pettibone system avoids the former, but not entirely the latter, which problem is now having the attention of producer builders. I may say that this tar destruction is the one feature of the Loomis-Pettibone system which has brought it to the front. In this system crude gas is drawn down through a secondary fire-bed and fixes the tar, but in so doing some of the product comes out as lampblack, which is almost impossible to separate by washing. At the present time apparently the only way to separate it is by a scrubber of the centrifugal type.

At the plant at Depew, N. Y., considerable lampblack is produced, but it is not very troublesome. If allowed to accumulate, it will fill up the 12-inch gas main from the holder in perhaps a couple of weeks, but it can at any time be readily flushed out with water, and presents no operative difficulty, except the dirt.

The tar question, in regard to the comparative value of fuels, is an interesting one. In a recent study of the tar content in the coal tested at St. Louis, I found a fairly accurate curved relation between the tar produced and heating value. The higher the latter, the more tar produced—in some cases, as high as 600 pounds per ton of coal; in others, barely 100 pounds. Evidently, therefore, the fixation of the tar adds considerably to the over-all producer efficiency.

It may be interesting in this connection to know that in some of the St. Louis tests the rotary tar extractor has been dispensed with by simply using the shell of the economizer from which the original air-heating tubes had been removed. This shell was fitted up with internal baffles to intercept the tar held in suspension in the crude gas. But this, of course, could hardly be recommended as a practical condition.

That efficient gas cleaning can be accomplished has been demonstrated in the blast furnace gas power plant of the Carnegie Steel Company, Pittsburg, Pa. The apparatus comprises a combination of vertical baffling washers in series with a centrifugal power scrubber, and can deliver gas to the holder cleaner than the surrounding air (Pittsburg air, of course).

Perhaps the most important problem in connection with the use of "dirty" gas in gas-engines is that of lubrication, but with the positive timing system the major difficulties have at least been overcome. In the Westinghouse system cylinder oil is introduced only on the induction stroke when the engine is drawing in its gaseous charge. In passing the oil ports the piston rings spread oil evenly over the inner surface so that the cylinder is lubricated in one out of every four strokes. A 500 h. p. double-acting gas-engine at the plant of the Carnegie Steel Co., at Bessemer, Pa., was operated four days on crude gas direct from the furnaces. At the end of this time it was taken apart and the dirt cleaned out of the valves and chambers. Besides quantities of dust, pieces of limestone, coke, and ore were found. Yet with this system of timed lubrication

the cylinders showed no abrasion, and both piston and gland rings were quite free.

Regarding the amount of steam used in a producer, $\frac{1}{3}$ pound per pound of coal gasified probably represents the minimum, and $2\frac{1}{2}$ pounds, as in the Mond by-product recovery system, about the maximum, the object of this excessive amount being to keep down the temperature of the fuel so as to preserve the by-products from disintegration. In the St. Louis tests the weights of steam varied from 0.3 to 0.6 pound per pound of Pocahontas coal. There is one difficulty in using too little steam; *i. e.*, in maintaining too high a temperature of fuel bed, the formation of clinker will result, especially with the low-grade cake coals. High temperature is the frequent source of clinker, and the further we depart from this, the better. This is perhaps the main reason why the Mond principle is so successful in handling low-grade fuels.

As to the holder capacity. This should be considered simply a question of operative insurance. It is not an absolute necessity, as explained in the preceding paper. Of course, the case of a single producer is somewhat similar to that of a single boiler. A boiler *may* give trouble; likewise, the producer. A duplicate should, therefore, be installed in each case, if the situation warrants. To my knowledge, a single case has not arisen where more than one producer is installed on the system above outlined that absolutely required a holder for continuous service. How much, then, are you willing to put to your equipment to insure against *possible* interruption? It seems exactly analogous to storage battery reserve. One man will consider a certain investment in storage batteries sufficient to insure normal working condition; another will duplicate it; a third will depend entirely on his prime movers.

Referring again to the comparative cost of anthracite and bituminous gas, I have obtained some recent coal prices for Philadelphia to supplement those in the paper: Good steam coal, \$2.85; slack and screenings, \$2.75; West Virginia gas coal, \$2.95; Westmoreland gas coal, \$3.30. In the paper we considered as a suitable anthracite fuel a mixture of Buckwheat, Rice, and Barley. This will average about \$2 per ton, or perhaps less if not sized; *i. e.*, all below Pea and Culm. I am informed that this unsized fuel can be turned out at the mines without great difficulty provided there is sufficient demand for it.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, April 6, 1907.—President Quimby in the chair. Sixty-eight members and visitors present.

The President announced the death of Mr. J. P. Webster, active member, who died March 27, 1907.

The Secretary read a communication from the T Square Club inviting the members to a meeting at the Pennsylvania Academy of Fine Arts.

Mr. C. J. Dougherty presented a paper on "The Electrical Plant and Means of Interior Communication of a Modern Ocean-Going Passenger and Cargo Vessel."

The Tellers reported the election of C. W. T. Barker, W. R. Conard, Wm. H. Ford, John M. Ruegenberg, and C. T. Wunder to active membership; Samuel Sinclair, 4th, and H. E. Snyder, to junior membership; and Carl A. Dickel to associate membership.

The President announced the appointment of Past-President McBride to represent the Club at the dedication of the New Engineering Building in New York City, April 16th and 17th.

Regular Meeting, April 20, 1907.—President Quimby in the chair. Seventy-six members and visitors present.

The President announced the death of Mr. Wm. H. Derbyshire, active member, who died April 13, 1907.

Mr. James Christie presented a paper on "Observations on Some Physical Characteristics of Cast-Iron."

Dr. Henry Leffmann presented a paper on the opening of streets through the grounds of Girard College.

Regular Meeting, May 4, 1907.—President Quimby in the chair. Ninety members and visitors.

The President announced that a meeting of those interested in the use of filter presses in connection with the treatment of slimes, ores, etc., would be held on May 7th, in the Club rooms.

Mr. J. R. Bibbins presented a paper on "Notes on the Use of Producer Gas for Power Purposes."

Regular Meeting, May 18, 1907.—President Quimby in the chair. Sixty-five members and visitors present.

The President announced the deaths of Mr. Charles H. Haswell, honorary member, who died on May 12, 1907, and of Mr. Willis L. Essen, junior member, who died May 8, 1907.

Mr. W. S. Vaux presented a paper on "Modern Glaciers: Their Movements and the Methods of Observing Them."

Past-Presidents Rudolph Hering, Washington Jones, and Henry G. Morris were appointed a committee to prepare a Memorial on the death of Mr. Chas. H. Haswell.

Business Meeting, June 1, 1907.—President Quimby in the chair. Seventy members and visitors present.

The Nominating Committee, nominated by the Board of Directors, was announced as follows: Thos. C. McBride, Chairman, S. G. Comfort, W. B. Riegner, E. M. Nichols, and Wm. E. Bradley.

Mr. S. S. Eveland presented a paper on "Ball and Roller Bearings in Practical Operation."

The tellers announced the election of W. H. Hansell to active membership; Chas. H. Dading to junior membership; and H. P. Childs to associate membership.

Special Meeting, July 1, 1907.—President Quimby in the chair. Sixty members present.

The meeting was called to take action on the proposition of leasing the property No. 1317 Spruce Street as a Club-house.

The following motion was introduced: "*First:* That it is the sense of this meeting that the Board of Directors should proceed to execute the lease of the property No. 1317 Spruce Street, for a term of three years, at an annual rental of $4000, with the option of purchase during the period for which the lease is taken. *Second:* That if deemed necessary to the successful carrying out of the project, an amendment to the By-Laws should be made, increasing the dues." An amendment was then offered that the motion should be divided so that the two sections should be voted on separately. Upon a rising vote this action was declared lost by 24 to 25. The original motion was then carried unanimously.

Among those present were President Quimby; Past-Presidents Comfort, Falkenau, Hartley, Hering, Marburg, McBride, and Spangler; and Messrs. Bascom, Bernstein, Corson, Dallett, Davis, Devereux, Dodge, Dow, Easby, Eddowes, Ehlers, Edwin M. Evans, Fairchild, Fuller, Gibson, Gowie, Gwilliam, Hagy, Hays, Hewitt, Holston, Latta, Locke, Maignen, Morton, E. M. Nichols, W. W. Nichols, Perring, Parker. Perrot, Riegner, Reeder, Silliman, Twells, Twining, Weiss, J. Chester Wilson, and Webb.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Regular Meeting, April 20, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Dodge, Ledoux, Loomis, and Perrot, the Secretary and the Treasurer.

The report of the Treasurer for the month of March was read and accepted as follows:

Balance February 28, 1907,	$6283.42
March Receipts,	570.00
	$6853.42
March Disbursements,	1017.72
Balance March 31, 1907,	$5835.70

It was moved and carried that the money now on hand in connection with the San Francisco fund should be returned to the subscribers.

The House Committee reported that an arrangement had been made for a new lantern at a cost of $160, of which $40 would be allowed for advertising.

It was moved and carried that the House Committee be authorized to make contracts for Bell and Keystone telephones, with extension sets for the lower floors, these extensions sets to be switched off when the office telephone is in use.

Past-President Christie addressed the Board regarding the proposal that the Club apply for accommodations in the proposed new building for the Franklin Institute. No action was taken by the Directors.

Regular Meeting, May 18, 1907.—Present: President Quimby, Directors Dodge, Easby, Loomis, and Perrot, the Secretary and the Treasurer.

The report of the Treasurer for the month of April was read and accepted as follows:

Balance March 31, 1907,	$5835.70
April Receipts,	385.00
	$6220.70
April Disbursements,	487.87
Balance April 30, 1907,	$5732.83

The House Committee reported that the new lantern had been purchased, and also that contracts had been made for the installation of the Bell and Keystone telephones as previously authorized.

It was moved and carried that two telephone booths be erected in the lower floor at a cost not to exceed $40 each.

It was moved and carried that a full set of the Proceedings should be bound and sent to the Technical Society of the Pacific Coast.

The Nominating Committee was nominated as follows: Thos. C. McBride, Chairman, S. G. Comfort, W. B. Riegner, E. M. Nichols, and Wm. E. Bradley.

It was moved and carried that the Secretary write to the Financial Secretary of the Samaritan Hospital, that the Constitution of the Club prohibits the Directors from taking any official action toward sustaining the work of the Hospital

Regular Meeting, June 15, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Dodge and Ledoux, and the Secretary.

The report of the Treasurer for the month of May was read and accepted as follows:

Balance April 30, 1907,	$5732.83
May Receipts,	265.00
	$5997.83
May Disbursements,	643.39
Balance May 31, 1907,	$5354.44

Special Meeting, June 24, 1907.—Present: President Quimby, Vice-President Devereux, Directors Dodge, Ledoux, and Loomis, the Secretary and the Treasurer.

The object of the meeting was to consider the proposition of leasing or purchasing No. 1317 Spruce Street as a Club House. It was moved and carried that a

call be sent out for a special meeting of the Club to be held on July 1st, at 8 o'clock.

The meeting was then adjourned until Wednesday, June 26th, at 8 o'clock.

Adjourned Special Meeting, June 26, 1907.—Present: President Quimby, Vice-Presidents Dallett and Devereux, Directors Dodge, Easby, Loomis, and Perrot, the Secretary and the Treasurer.

The subject of the proposed lease of No. 1317 Spruce Street as a Club House was discussed, with special reference to increase in expenditure and income. It was moved and carried that a statement of the financial aspect of the proposition be drawn up for presentation in a printed form at the special meeting of the Club on July 1st. It was moved and carried that in this statement the following increase in dues be suggested as likely to be necessary: Resident Active Members from $15 to $30; Resident Junior Members from $10 to $20; Resident Associate Members from $15 to $30; Non-Resident Active Members from $5 to $15; Non-Resident Junior Members from $5 to $10; Non-Resident Associate Members from $15 to $15.

It was moved and carried that the President, Secretary, and Treasurer be appointed a committee to prepare this statement for presentation to the Club.

ADDITIONS TO THE GENERAL LIBRARY.

From Interstate Commerce Commission.

Twentieth Annual Report, 1906.

From A. Gibb Maitland.

Prospects of Obtaining Artesian Water in the Kimberly District.

From C. B. Berry.

Reports of Proceedings of First, Second, and Third Annual Meetings of the Wood Preservers' Association, 1905, 1906, and 1907.

From John Crerar Library.

Twelfth Annual Report of The John Crerar Library for the Year 1906.

From University of Pennsylvania.

Proceedings of "University Day," February 22, 1907.

From Geological Survey of Western Australia.

Bulletin No. 24.

From Connecticut Society of Civil Engineers.

Paper and Transactions for 1906, and Proceedings of the Twenty-third Annual Meeting.

THE ENGINEERS' CLUB OF PHILADELPHIA

1122 Girard Street

OFFICERS FOR 1907

President

HENRY H. QUIMBY

Vice-Presidents

Term Expires January, 1908
WASHINGTON DEVEREUX

Term Expires January, 1909
W. P. DALLETT

Directors

Term Expires January, 1908

F. E. DODGE
WM. EASBY, JR.
FRANCIS HEAD

Term Expires January, 1909

J. W. LEDOUX
JOHN T. LOOMIS
EMILE G. PERROT

Secretary
WALTER LORING WEBB

Treasurer
GEORGE T. GWILLIAM

Clerk
MARJORY LAMBE

STANDING COMMITTEES OF BOARD OF DIRECTORS

Finance—W. P. Dallett, Wm. Easby, Jr., J. W. Ledoux.
Membership—Wm. Easby, Jr., F. E. Dodge, W. P. Dallett.
Publication—Emile G. Perrot, Wm. Easby, Jr., Francis Head.
Information—Francis Head, Washington Devereux, Emile G. Perrot.
Library—Washington Devereux, John T. Loomis, J. W. Ledoux.
House—John T. Loomis, Washington Devereux, F. E. Dodge.
Advertising—Geo. T. Gwilliam, Walter Loring Webb, Emile G. Perrot.

MEETINGS

Annual Meeting—3d Saturday of January, at 8 P.M.

Stated Meetings—1st and 3d Saturdays of each month, at 8 P.M., except between the fourteenth days of June and September.

Business Meetings—When required by the Constitution or By-Laws, when ordered by the President or the Board of Directors, or on the written request of five Active Members of the Club.

The Board of Directors meets on the 3d Saturday of each month, except July and August.

New Club-house—1317 Spruce Street.

Editors of other technical journals are invited to reprint articles from this journal, provided due credit be given the PROCEEDINGS.

PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. XXIV. OCTOBER, 1907. No. 4

THE NEW CLUB-HOUSE.

EXTRACT FROM BULLETIN OF OCTOBER 26, 1907.

THE Board of Directors desires to express its gratification with the action of the Club meeting on the 19th inst. in unanimously approving and confirming the action of the Board in its purchase of the premises No. 1317 Spruce Street, for the use of the Club, and presents herewith photographic views of the exterior and interior of the house and plans of the four floors.

The front building is 25 feet wide and 50 feet long; the back building is 19 feet wide and 90 feet long. The two rooms and hall on the second floor of the front building will be thrown into one large room for the Club meetings, making a space of 24 feet by 48 feet, with an alcove at the rear for the stereopticon. The seating capacity will be twice as great as that of the assembly room in the present house. During the time between meetings the rooms will be changed to constitute the library and reading room, and as it is both well lighted and removed from noise, it will undoubtedly be a most attractive room.

The large room in the second story back building will be made the billiard room, and the room in the rear of it will be the Club office.

The dining-room on the first floor is 20 feet by 30 feet, with a large bay window, paneled mahogany ceiling and mosaic floor. The kitchen and serving room appointments are all on a corresponding scale.

The two rooms of the first floor main building will be the lounging, smoking and conversation rooms.

A coat room will be constructed off the first floor stair hall, and a wash room in the basement.

The interior finish—woodwork, parquetry floors, mantels, etc.—is rich and tasteful; the room is ample, the location convenient, and it is confidently hoped that the superior accommodation that the members will enjoy there will attract them to the house as a place of resort and

STAIR HALL, SECOND STORY.

association, and will cause a large accession of new members. The prospect of the change to the new house has already brought a large number of applications, twenty-two of which are on the accompanying ballot for the election of members.

The Finance Committee of the Club reports encouraging responses to its invitation for subscriptions to the bond issue.

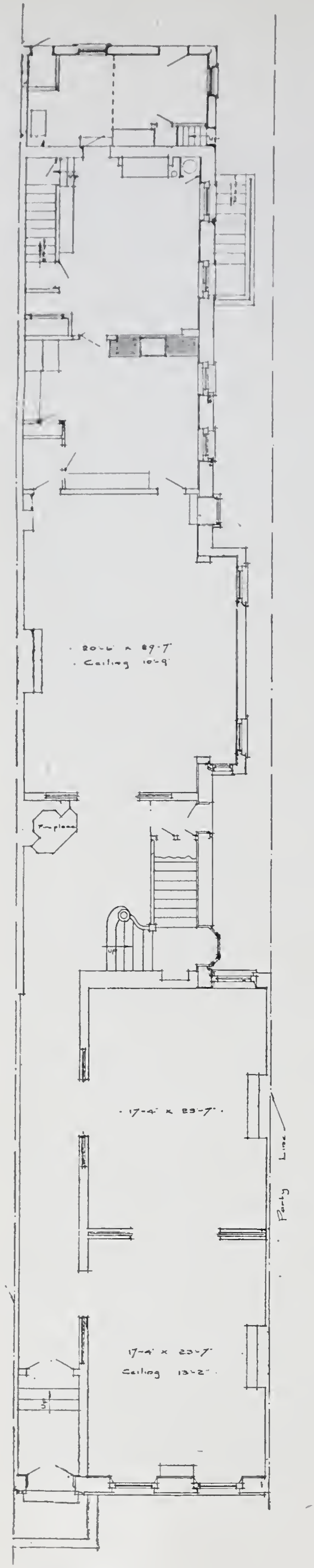
Lounging and Smoking Rooms, First Floor.

Stair Hall, Looking into Dining-room.

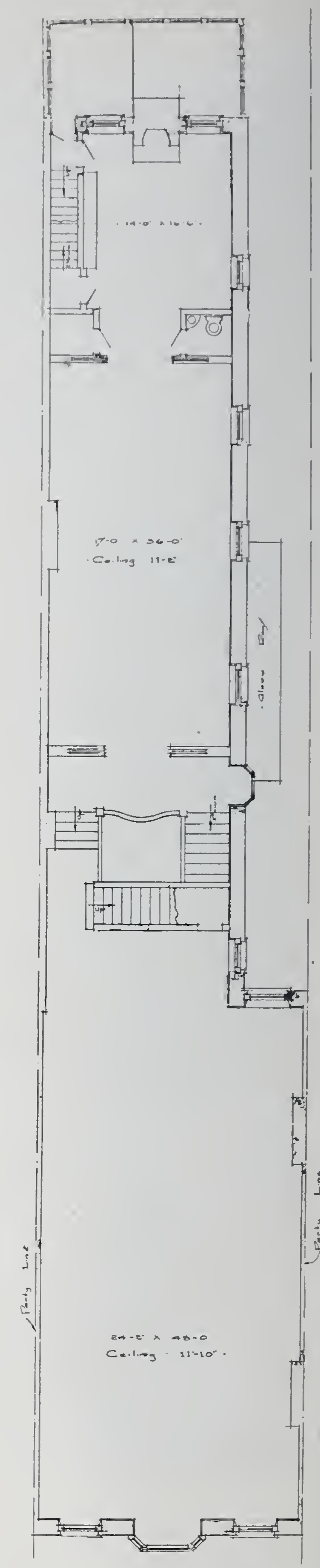
Billiard Room, Looking into Office in Rear.

Front End of Meeting Room, Second Floor (Before Alterations).

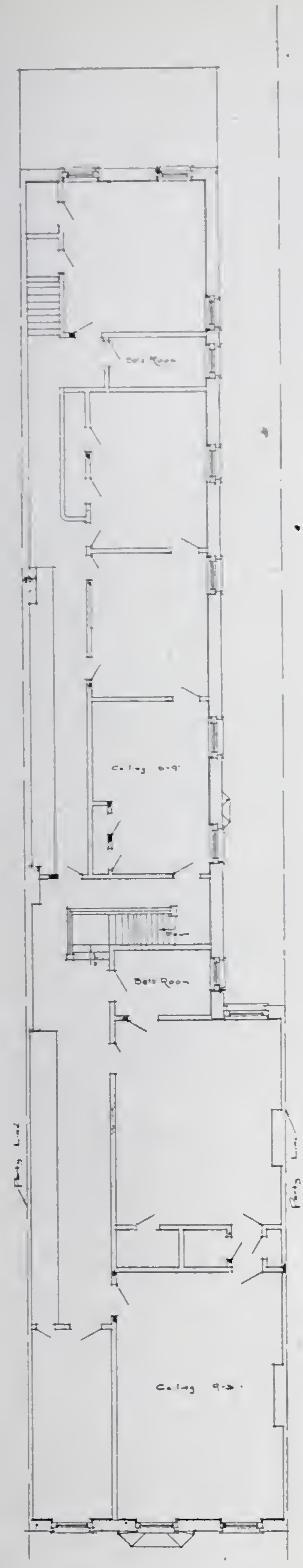
Rear of New Club-house.



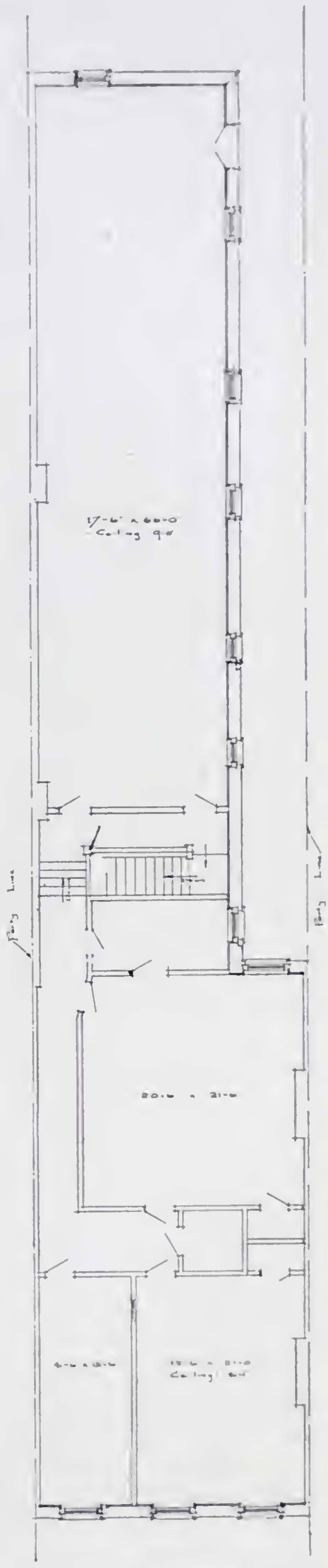
Plan of the First Floor.



Plan of the Second Floor.



PLAN OF THE THIRD FLOOR.



PLAN OF THE FOURTH FLOOR.

Paper No. 1042.

BALL AND ROLLER BEARINGS IN PRACTICAL OPERATION.

SAMUEL S. EVELAND,
Visitor.

Read June 1, 1907.

It is probable that with the possible exception of the automobile industry, no business has developed so rapidly during the past five years as is the case with the ball and roller bearing business. In 1902 there were several small concerns making ball bearings, employing a total force not exceeding one hundred men, women, and children; while at present fully three thousand are employed, and the industry has grown so rapidly that over $5,000,000 capital is invested in the business.

The general and almost universal use of some form of anti-friction bearing makes it difficult to select applications of the principle having especial merit, although a few special cases may be mentioned where their use has not been notably successful. The field is too large to enter fully into detail, which can be more readily appreciated when it is understood that anti-friction bearings are sold for as little as one cent each and as high as $7000 for a single bearing, and are in use carrying loads from a few ounces running at 35,000 R.P.M. to loads in excess of 1,500,000 pounds at 100 R.P.M. Some evidence of the range in values in the steel ball business alone is shown in the commercial sizes, which are from $\frac{1}{32}$ of an inch to 6 inches inclusive.

It would be desirable if possible to give a formula to work to in making anti-friction ball and roller bearings; but such a formula does not exist.

It is probable that one may be developed in the future, but at present there is not sufficient reliable data upon which to base a theory that will work out practically in all or even in a majority of cases. Some foreign manufacturers of balls have issued statements giving a number of theories, but they do not appear to be reliable, as they change them frequently.

As a rule, engineers do not clearly understand ball and roller bearings. They are made for every conceivable purpose, and if it was possible

to have a formula to work to, the manufacturers would willingly supply it, so that engineers would feel more free to design their own anti-friction bearings. From an engineering standpoint, it would seem unreasonable to state that a formula cannot be figured out that will give fair results for nearly all cases, but it is a fact that it has been impossible to do so, largely because many more points have to be taken into consideration with an anti-friction bearing than with a babbitt or plain bearing, and satisfactory data on the subject have not yet been secured.

In designing a babbitt bearing it is not necessary to consider the diameter of the shaft, class of material used in the shaft, what the babbitt is made of, the material used in the cast-iron box containing the babbitt, and the length of the bearing, in addition to the weight and revolutions per minute; but all of these have to be taken into account with ball or roller bearings. A properly designed ball or roller bearing has to be made with extreme accuracy of finish, and of hardened steel, depending upon the work the bearing has to perform, and all of the other points above referred to have to be taken into consideration. Some knowledge of the degree of accuracy required in ball bearings is shown in the fact that the finest balls made do not vary over .0001 of an inch either in sphericity or diameter, comparing one ball with another. It was formerly the practice to make all ball bearings of machinery steel, case-hardened, but this does not give good satisfaction for heavy loads or high speeds, where a high-grade carbon or tool steel or a special alloy steel is required. Some evidence of the value of this is shown in the fact that a ball made of high-carbon steel ½ inch diameter will crush under a pressure of about 25,000 pounds, but by making them out of "standard alloy" steel it takes from 50,000 to 60,000 pounds to crush the same size.

A few years ago it was considered very satisfactory if balls did not vary over .001 of an inch, while at present the best balls do not vary over .0001 of an inch. While the ball manufacturer has greatly improved the accuracy and finish of his product, many users have met with failure by attempting to apply the balls to races, cups, or cones varying several thousandths of an inch, under which conditions it is impossible to secure satisfaction.

Notwithstanding the rapid growth of the business, in which several thousand hands are now employed, it is still in its infancy, and the underlying rules governing it mechanically, from an engineering standpoint are not understood. Unless some essential points are

correct in the application of the bearing, even when properly designed it will not give satisfaction. An anti-friction bearing may be made true to size, but they are often used where the parts with which they come in contact are badly out of line or untrue, in consequence of which the load is forced on a few balls, making it impossible to secure satisfactory results.

Some evidence of the importance of finishing bearings accurately is shown in a test recently made by the United States Government on a revolving lighthouse lens. The Government engineers and mechanics designed and made in the Government shops a type of ball bearing that was finished true to .001 of an inch to .002 of an inch, which was fitted with ordinary commercial balls, purchased from a jobber in New York City, which also varied in size. A ball bearing manufacturer was also invited to furnish a bearing of his own design for testing, in comparison with the Government bearing, a ball bearing made true both in plates and balls so that the variation was limited to .0001 of an inch. The lens, measuring about seven feet in diameter and weighing 3000 pounds, was mounted on a thrust or step bearing, and revolved by weighted clockwork, the rapidity of the revolutions being regulated by the amount of weight used.

Fig. 1.—Revolving Lighthouse Lens Mounted on Ball Bearings.

The tests made and results obtained were as follows:

(A) Weight required to revolve lens, with ordinary grooved bronze and steel plate thrust and making one revolution in thirty seconds, was 900 pounds.

(B) Weight required for Government ball bearing, one revolution, twenty-five seconds, 123 pounds.

(C) Weight with manufacturer's special, accurate ball bearing, one revolution, in thirteen seconds, 63 pounds.

(D) Weight with special plates, but ordinary (Government) balls, one revolution, twenty seconds, 73 pounds.

Another test was made to show the pressure required to move it when exerted against the rim or outer circumference of the lens. In this test the Government ball bearing required 64 ounces, but only

½ ounce was required for the special ball bearing, and three ounces for the special plates and Government balls.

One point that has been misunderstood in the past is that a ball or roller bearing requires oiling, exactly the same as any other piece of machinery. Only a small amount is consumed, but it is absolutely necessary, both as a lubricant and in order to prevent rust, due to condensation or other causes.

Both ball and roller bearings, to give the best satisfaction, should be made of steel, hardened and ground, accurately fitted, and in proper alignment with the shaft and load; cleaned and oiled regularly and fitted with as large sized balls or rollers as possible, depending upon the revolutions per minute and load to be carried. If used as above

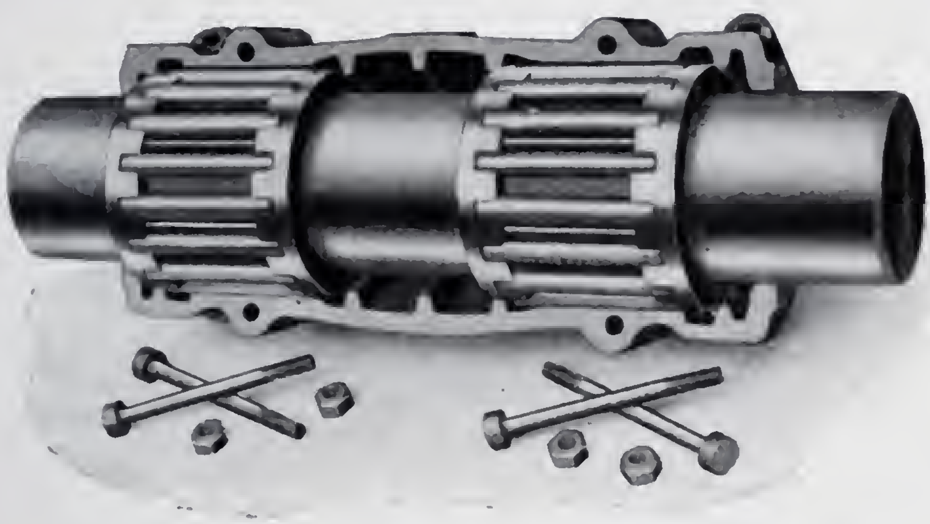


Fig. 2.—Roller Bearing Shafting Hangers.

recommended, they will return their cost many times over in power and oil saved, in a very short time.

Roller bearings are generally considered practically the same as ball bearings, although this is not the case, as a ball of any size runs only upon a small point, while a roller bearing is distinctly a "line" bearing, and is capable of carrying loads greatly in excess of that which a ball bearing of the same size will carry. To secure satisfactory results, the rollers should be of steel, hardened and ground, and they should be run upon hardened and ground steel surfaces. The rolling action of the bearing, if run on cast-iron, grinds it into a powder, while if it is run on soft steel, it condenses the metal, causing the bearing to become loose.

The saving in power varies, depending upon the conditions under which the bearings are used, and whether they are kept clean, oiled, and in proper alignment. It required 49 horse-power to drive certain

machines run with plain babbitt shaft hanger bearings, while the same machines required 27 horse-power when run with roller bearing hangers, showing a saving of 22 H.P. The friction loss in line shafting is much greater than generally realized. Prof. Flather, of Purdue University, secured data on this subject in which it is shown that the average frictional loss in fourteen manufacturing plants varied from 15 per cent. to 80 per cent. The report is as follows:

Firm Name.	Kind of Work Done.	Total H.P.	H.P. to Drive Shftg.	H.P. to Drive Mchry.	Percentage of Total to Shftg.
J. A. Fay & Co.	Woodworking machinery	100	15	85	.15
Union Iron Works	Engines & mining mchry	400	95	305	.23
Frontier Iron and Brass	Marine engines	25	8	17	.32
Taylor Mfg. Co.	Automatic Engines	95	—	—	—
Baldwin Loco. Works	Locomotives	2500	2000	500	.80
William Sellers & Co.	Heavy mach. one dept.	102.45	40.89	61.56	.40
Pond Machine Tool Wks.	Machine tools	180	75	105	.41
Pratt & Whitney Co.	Machine tools	120	—	—	—
Yale & Towne Co.	Cranes and tools	135.05	66.81	68.24	.49
Ferra Auto. Mch. Co.	Pressed dies	35	11	24	.31
T. B. Wood's Sons	Pulleys and shaftings	12	—	—	—
Bridgeport Forge Co.	Heavy forgings	150	75	75	.50
Singer Mfg. Co.	Sewing machines	1300	—	—	—
Hartford Machine Screw Co.	Machine screws	400	100	300	.25
Average					$38\frac{4}{10}$

The United States Government tested an army wagon equipped with and without roller bearings. The result showed a saving in pull required to move the wagon on asphalt, 75 per cent.; Belgian block, 60 per cent.; common dirt road, 55 per cent.; and in starting load on each of the above, 65, 55, and 53 per cent.

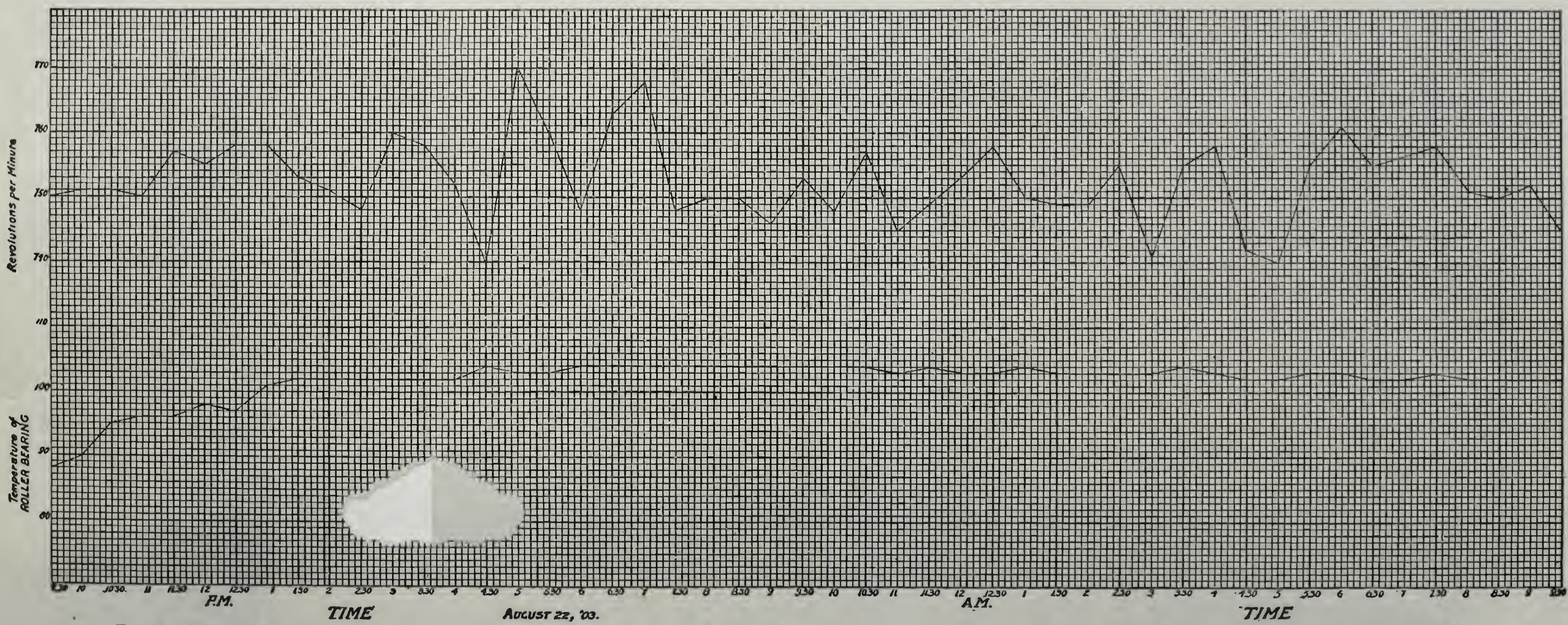


FIG. 3.—TEST OF STANDARD PLAIN ROLLER THRUST BEARING. DURATION OF TEST, TWENTY-FOUR HOURS. WEIGHT, 2760 POUNDS. SPEED, 750 TO 770 R.P.M.

TRACTOGRAPHIC TESTS WITH A UNITED STATES ARMY WAGON HAVING STANDARD ROLLER BEARING AXLES.

Asphalt, test with common axle	100	pounds	pull
Asphalt with roller bearing axle	25	"	"
Asphalt with common axle, starting load	450	"	"
Asphalt with roller bearing axle, starting load	220	"	"
Asphalt with 8 per cent. grade common axle	400	"	"
Asphalt with 8 per cent. grade roller bearing axle	170	"	"
Belgian block, common axle	165	"	"
Belgian block, roller bearing axle	75	"	"
Dirt road, common axle	260	"	"
Dirt road, roller bearing	100	"	"
Dirt, starting common axle	850	"	"
Dirt, starting roller bearing axle	400	"	"

An upright drill that will drill only a $\frac{5}{8}$-inch hole will drill a hole $1\frac{1}{4}$ inches in diameter when fitted with a roller thrust to take the end strain.

The steam yacht "Aphrodite," 3300 horse-power, reported an increase in speed of 8 per cent., as well as a saving in coal of over five tons daily, secured by the use of roller thrust propeller bearings. Some thirty other vessels report equally good results, as well as a great saving in oil and a reduction in vibration.

The National Tube Company have used several roller thrusts 18-inch diameter for five years, which show less than .003 of an inch wear, although run with a load of 100,000 pounds at 120 revolutions per minute, sixteen hours daily.

A roller thrust used on a vertical motor made a test run (see diagram fig. 3) of twenty-four hours, with a load of 2750 pounds at 740 to 770 revolutions per minute. It was run absolutely without oil (which was due to a misunderstanding), but the highest temperature it reached was 104° F. The temperature of the air in the pit where it was located was 96° F., showing only 8 degrees rise.

The largest anti-friction bearing ever made has recently been tested at Niagara Falls on a 5500 horse-power unit, the rotary weight on the bearing under normal conditions being about 156,000 pounds. Under extreme conditions of head and tail water levels the load on thrust was increased by suction, etc., to a total of 190,000 pounds. The normal speed is 250 revolutions per minute, but if control is lost of the governor, it may reach double that speed, or 500 revolutions per minute.

The following specifications cover the conditions under which the

test was made, and which was extremely severe, so as to cover all possible contingencies:

(A) With normal working pressure on balancing piston, start machine at 50 revolutions per minute; run six hours, raise speed to 75 revolutions per minute; run two hours; continue process until speed has reached 250 revolutions per minute.

(B) Raise speed as rapidly as possible to 350 revolutions per minute, run five minutes, then reduce speed as rapidly as possible, to zero.

(C) Raise speed quickly to 250 revolutions per minute with normal working pressure on balancing piston; run one hour to determine whether bearing is in proper running condition, after test "B". Apply

Fig. 4.—Roller Thrust, Niagara Test, 5500 H.P., 190,000 Pounds Load.

load to generator in increments of 1000 horse-power, running one hour under each load; run maximum load of 6000 horse-power if possible.

(D) Reduce pressure under balancing piston by decrements of five pounds per square inch until water is entirely cut off from under the piston, maintaining the speed at 250 revolutions per minute and running one hour at each pressure with full load of generator.

(E) Drop load suddenly, allowing the speed to rise as high as governor will permit under its normal adjustment.

The results of the test were taken every half hour for the entire period. The old-style thrust bearings are composed of heavy cast-iron discs, accurately faced and provided with oil grooves running to the circum-

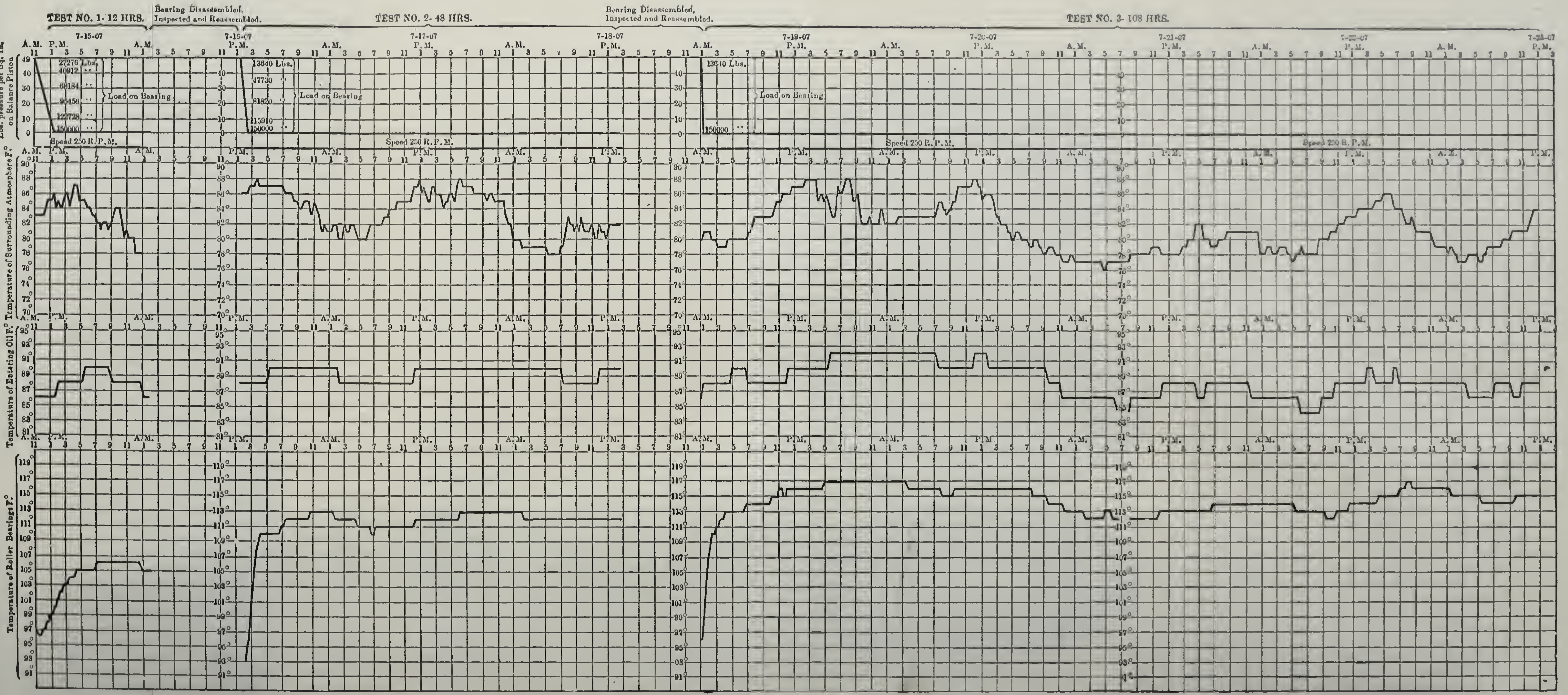


Fig. 5.—Niagara Falls Test Run Roller Thrust. Temperature and Load Curves Plotted from the Final Test. Load 150,000 Pounds. 250 R.P.M.

ference and inclosed in tight casings, provided with plates and dead lights, through which the bearings and thermometers in the oil may be observed. Oil is furnished at about 50 pounds pressure by a set of triple-acting pumps for each thrust. If by accident or otherwise the pump stops, the cast-iron thrust discs burn out at once. When this happens, it involves removing the thrust, casing, and disc, lifting shaft, filling with new discs, as well as a loss of 5500 horse-power, for at least twenty-four hours. The labor required for attending to the pumps amounts to about $2000 per year, exclusive of cost of power, oil waste, repairs, etc.

In order to lighten the duty of the thrust bearings, a balance piston is fitted in casing at bottom of each shaft and designed to counterbalance the entire weight of the dynamo, shafting, and runner. Water is admitted to this piston at about 55 pounds per square inch, and can be adjusted by valves as required. If this pressure is removed, the entire weight of at least 190,000 pounds is thrown on the thrust bearing. This may occur by shutting off the pressure through accident to the valves and piping, or, as frequently occurs in winter, by the water passages becoming clogged with ice, and when this takes place, the cast-iron thrust discs burn out at once, throwing out of commission machinery costing over $500,000 and shutting down the plant for at least two weeks. The plain roller thrust above mentioned was tried under all the above conditions of load and overload, in an effort to damage or break it. In one of the tests, under conditions where the old-style thrust lasted less than one minute, the roller thrust ran for four hours, or two hundred and forty minutes, and showed absolutely no wear; and at the end of all of the tests the bearing was in perfect condition in all respects, and less than 10 per cent. of the oil formerly used was consumed.

There was another test made of the same general character after the bearing had been in use over two years, which proved equally satisfactory, the general result of which is shown in the diagram (Fig. 5).

In considering the use of plain roller thrust bearings for generators and similar purposes, it would be very desirable, if possible, to give accurate data regarding the frictional loss as compared to oil pressure bearings. It is impossible, however, to supply this information, although the experience with the Niagara Falls bearing above referred to is of some value. The load carried in the case referred to was about 200,000 pounds, and in a test run as shown in the diagram

(Fig. 5), it was found that the bearing did not heat. It was also found that it was not possible to separate the friction loss of the thrust bearing from that of the guiding bearings and governor driving gears in the main shaft of the turbine, but, as it required the same amount of power to run the unloaded generators with the roller thrust bearing installed as it did to accomplish the same work with the oil thrust bearing, it would appear that there is no material difference between the two forms. Some years ago there was a test made of a high-pressure oil

Fig. 6.—Conical or Tapered Roller Thrust.

bearing at Niagara Falls, in which it was found that the frictional resistance was so low that the leakage water caused the turbine to rotate at such a high speed that the brake would not hold. With a load of approximately 150,000 pounds on the thrust it was possible to start rotation with a pull of 15 pounds on the outside of the field ring at about six feet radius, or, in other words, a man with a pull of 15 pounds could start in motion 150,000 pounds. In another test run on a 2000 K. W. rotary generator the same approximate data were secured,

while the temperature of the outgoing oil was only raised 14° C. beyond the temperature of the oil as it entered the bearing.

It has been found that while a tapered roller thrust having conical rollers (Fig. 6) is theoretically better, it is not so in actual operation. The United States Government made some extensive experiments with the two forms of bearings, each carrying loads of nearly 100,000 pounds, and it was found that the conical roller thrust, when made as accurately as was possible mechanically, would fail or show serious distress after running less than an hour, while a plain roller thrust ran for many days without difficulty. Other forms of conical roller thrust were then made, but all developed the same trouble.

It is probable that the principal trouble with the conical thrust bearings is due to the fact that it is practically impossible for commercial bearings to be finished as accurately as is needed to secure perfect results. Each tapered roller, as well as the beveled plates, must be ground to the greatest degree of accuracy, and as there is no method of accurately measuring beveled pieces, it is practically impossible to have them uniform, the result being that the long rollers attempt to twist or turn, causing trouble in operation.

For high-speed loads ball bearings are generally more desirable than roller bearings, although this rule cannot always be adhered to, as the weight carried and general conditions under which the bearings are used must be taken into consideration. There are various forms of grooved ball bearings, but the most satisfactory in operation is usually found to be the form having grooves a trifle larger than the radius of the ball, so that a considerable portion of the weight or strain comes upon the balls instead of bearing only upon one or more points of contact.

The anti-friction bearing used in the above test was the standard plain roller thrust bearing, which does not usually commend itself to engineers, as it is apparently not theoretically correct in construction. Several hundred thousand bearings of this type are in actual operation, and for practical results they give better satisfaction and are more durable than any other form of thrust bearing, including ball thrust, conical roller thrust, etc., especially for heavy loads.

Many bearings are in successful operation of this type carrying moderate loads running as high as 3500 R.P.M., as well as others carrying loads at low speeds in excess of one million and a half pounds, and as these have been in service for several years, it is believed the device has proved itself of value and merit.

It consists of two steel plates, hardened and ground, with a cage or retainer to carry the rolls, which are also of steel, hardened and ground. The rollers are not tapered or conical, but are made in short sections, so that they turn readily, and any "slippage" that takes place does not cause trouble of any character.

In actual practice it has been found that the bearing will sustain loads ranging from four to eight times the weight that a ball thrust bearing of the same dimensions will carry. It is especially desirable for use to take the thrust of worm wheels, turbines, generators, centrifugal pumps, etc., as well as propeller shafts of steam-vessels, where it has increased speed from one-half to one knot per hour, at the same time reducing fuel and oil consumption, saving wear and tear upon the engine, and reducing vibration to a minimum.

Exceptional success has been secured with the use of this bearing upon large generators, rotary converters, etc., carrying loads from

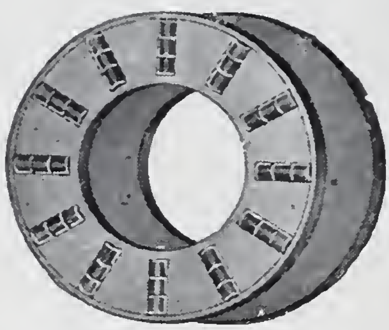


Fig. 7.—Plain Roller Thrust Bearing.

10,000 pounds up to 200,000 pounds at speeds ranging from 200 to 1200 R.P.M.

For loads running at high speed, a ball is inserted at the end of the rollers to care for the outer thrust or strain. The rollers are "staggered" so that the entire plate or washer upon which they revolve is covered by the rolls.

In order to secure the best satisfaction from any anti-friction thrust bearing, it is necessary to have it properly oiled and to have the bearing run in alignment with the shaft and load. If a bearing does not run true, the load will come upon one side of the bearing more than upon the other, in this manner retarding some of the rollers, thereby reducing efficiency of the bearing and possibly causing difficulty in operation.

The bearings are finished very accurately, all parts being carefully ground, and it is recognized that it is difficult for machinery builders to finish their parts as accurately as the roller bearings are finished.

In applying these bearings in locations of this character, it is desira-

ble to use some form leveling device, designs for which are given in the illustrations. These leveling or self-aligning parts consist of convex

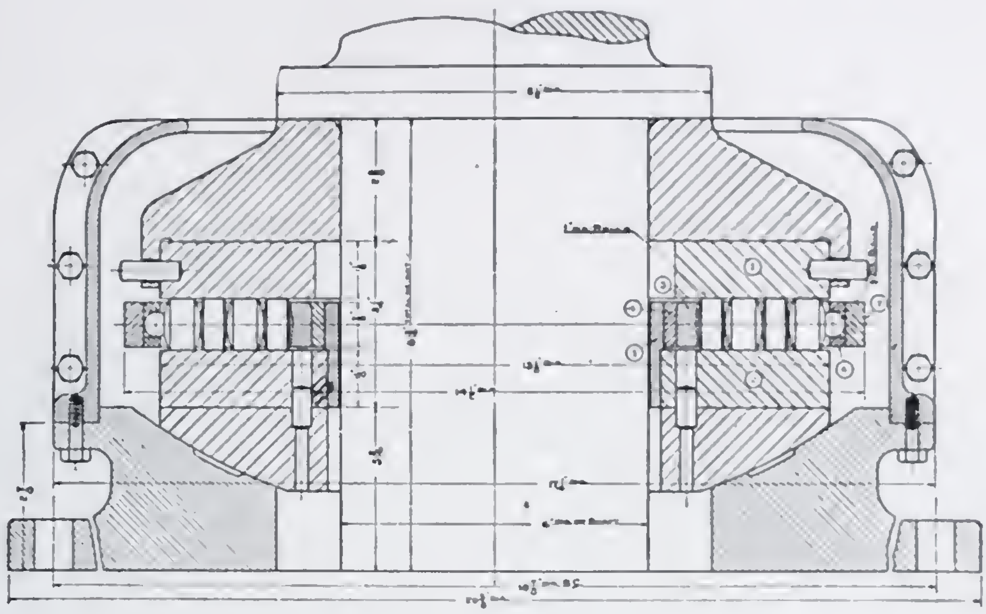


FIG. 8.—ROLLER THRUST FOR GENERATOR, SHOWING LEVELING DEVICE AND OIL RESERVOIR.

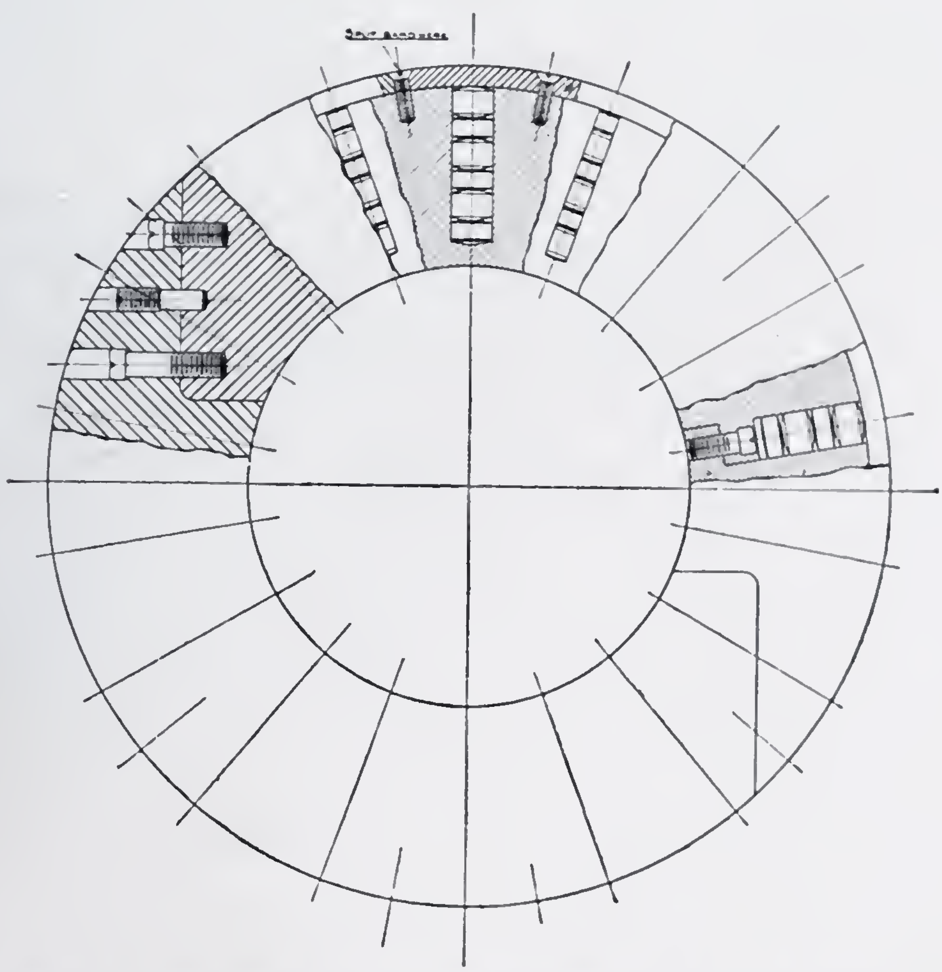


FIG. 9.—PLAIN ROLLER THRUST SPLIT OR IN HALVES.

and concave washers upon which the roller bearing rests and which will care for any inequality in the parts against which the bearing is applied.

Any other form of leveling device can be used that will give satisfactory service. There are also shown in the illustrations methods of lubricating the bearing, some form of which should be used, as oil is required, although a very small amount is consumed.

Fig. 10.—Standard Roller Thrust Propeller Bearing.

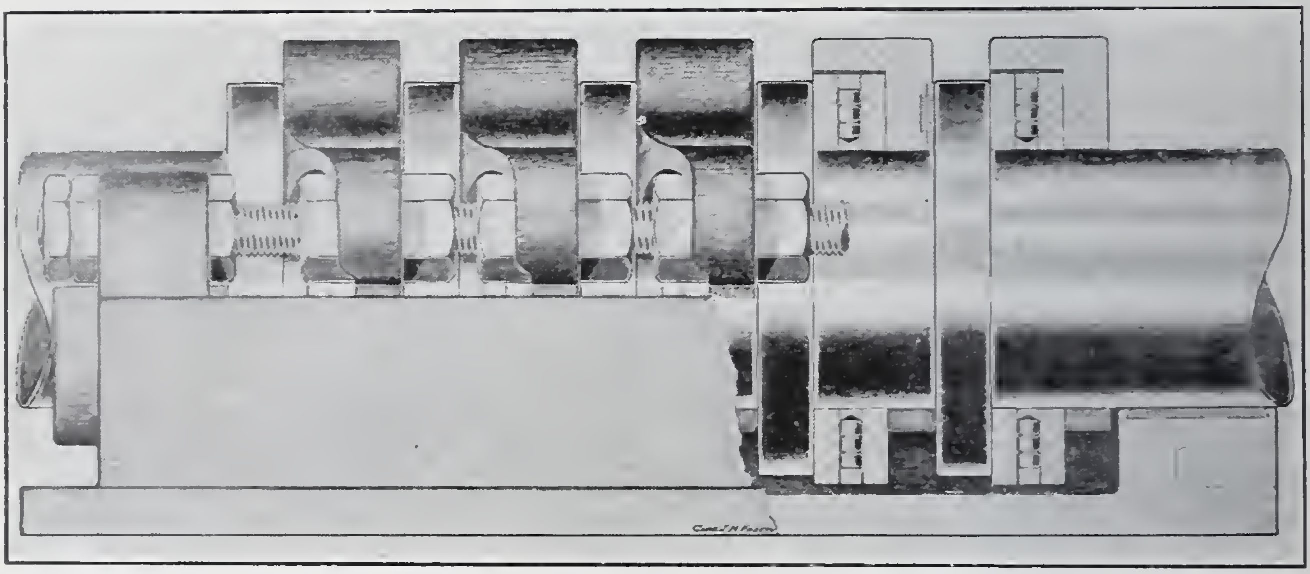


Fig. 11.—Roller Thrust Propeller Bearing and Shaft.

The washers are accurately finished on both sides, so that if desired the two bearing surfaces may be reversed if wear should take place after being in operation some years. It has not, however, been found necessary in long experience to reverse the washers, as the wear is so slight as not to be of importance.

The ordinary form of bearing is made solid, but they are also furnished split or in halves with all joints accurately ground and which give equally as good service as the solid plates. They are somewhat more expensive than the solid bearings, but are especially desirable for use where it may become desirable to remove them, as it is then not necessary to dismantle a machine or generator upon which they have been applied, as they can be taken apart by removing the screws which hold them in place without disturbing any parts of the machine upon which they are used.

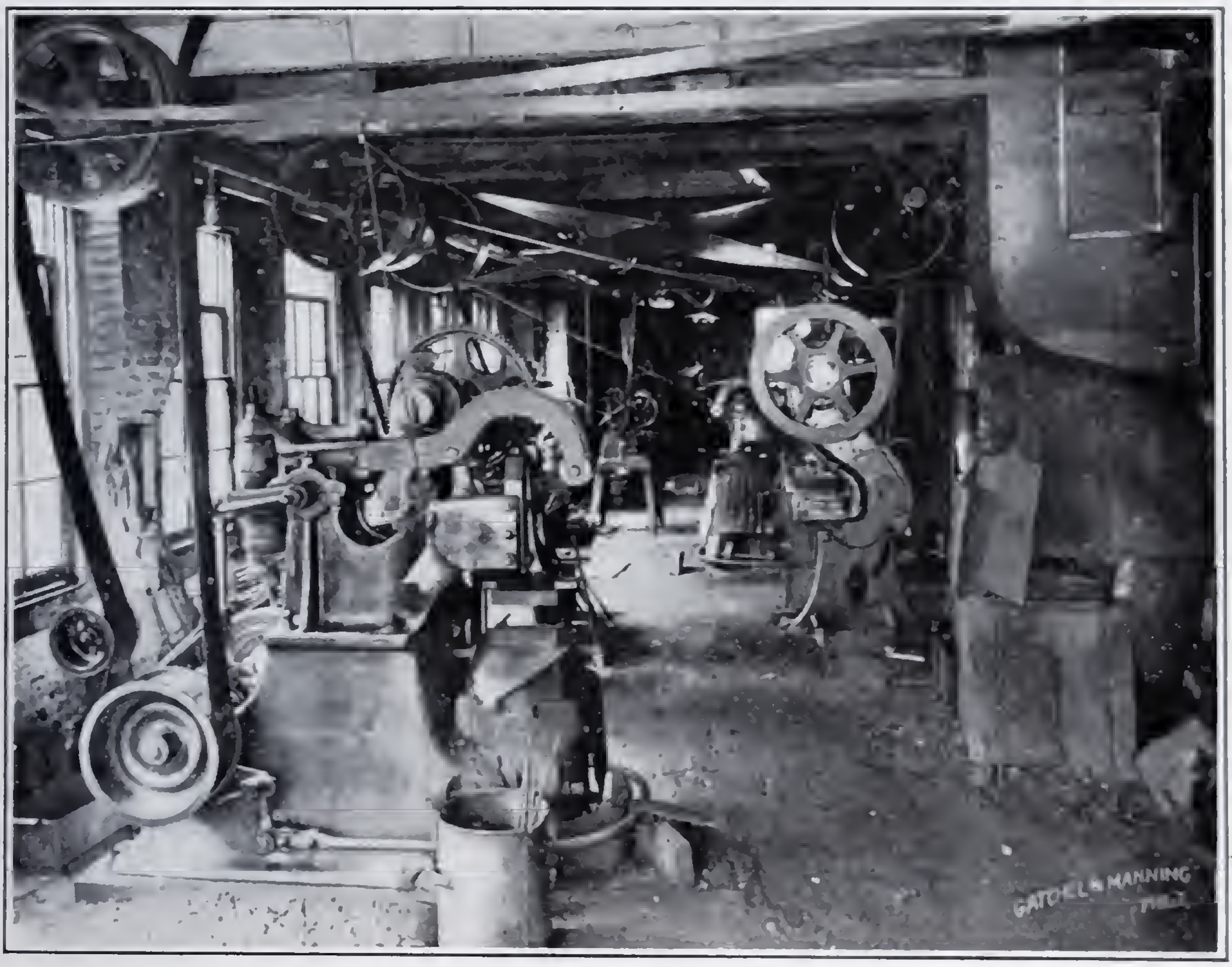


FIG. 12.—BALL FORGING HAMMERS.

The bearings are especially desirable to take the place of the ordinary marine or propeller thrust type of bearing, which latter usually require a water jacket to keep them cool, but which is not required for plain roller thrust bearings. Small sizes of roller thrust bearings are furnished with washers of machinery steel, case hardened and ground, but for generators, turbines, and heavy work, special standard alloy tool steel is used, both in the rollers, plates, and washers, which steel is exceptionally tough, strong, and durable.

Manufacturing Balls.

The methods used in manufacturing balls are interesting and not generally understood. The larger sizes are forged, several balls being made at one time on string or duplicate dies used in a form of helve hammer, as shown in the illustration (Fig. 12); others are turned in automatic machines, as many as 30,000 a day being made of one size by one machine, and some are made in presses. They are then rough ground on machines fitted with large emery wheels revolving at about

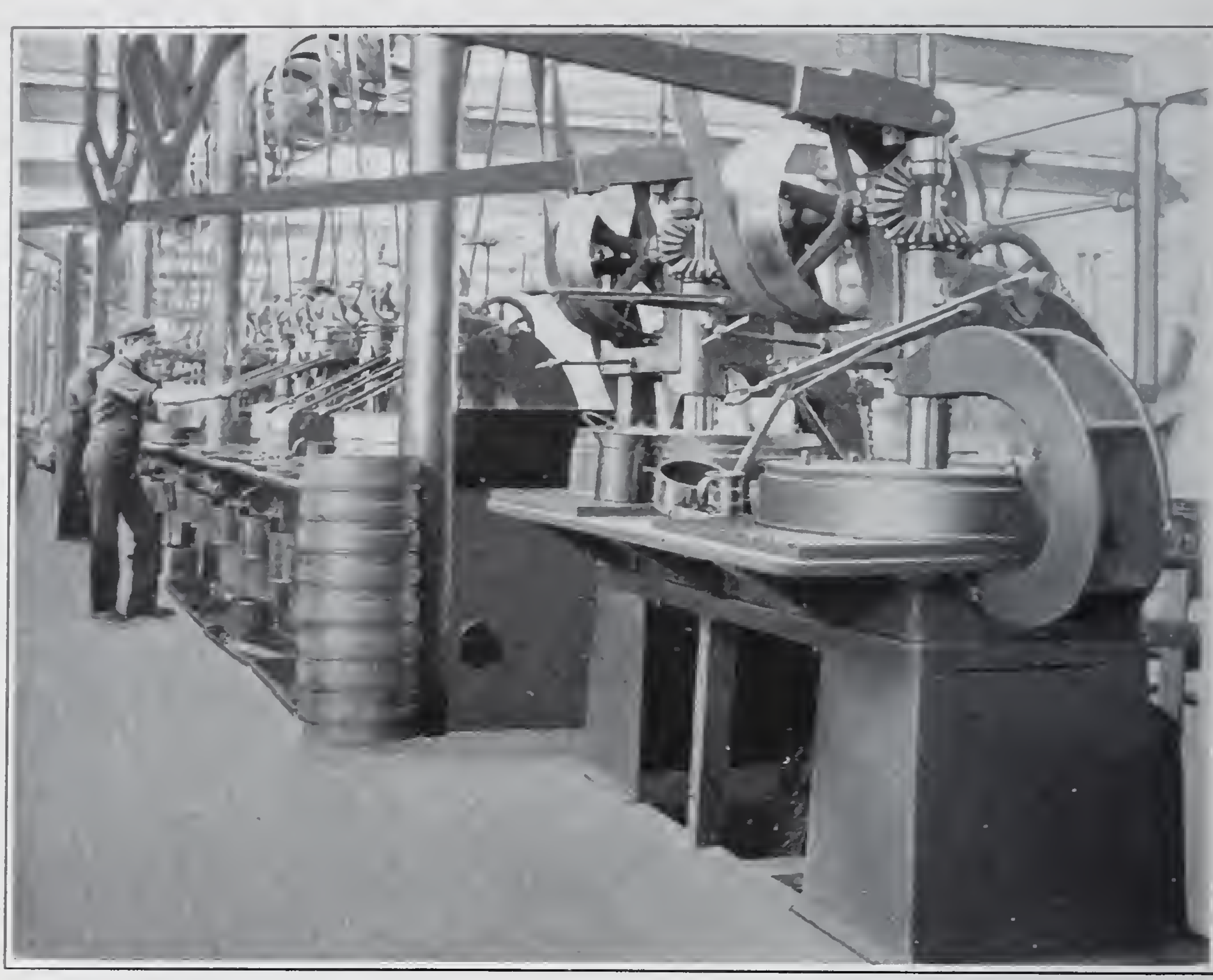


Fig. 13.—Ball Grinders.

1300 R.P.M.; after which they are run in an oil grinding machine (Fig. 13) in which oil and emery and other materials are used, the balls running in a groove in the mixture referred to.

It is impossible to have all balls come through these grinding operations absolutely uniform in diameter, and they are therefore gauged (Fig. 14), each size being packed separately. Quarter-inch balls, for instance, are packed in boxes which are carefully marked as containing balls exactly .250 of an inch in diameter, while another box will contain balls one-quarter of a thousandth above or below that

size, or one-half thousandth, and so on according to the size of the ball. This fact is not generally understood, and frequently those desiring to use balls will mix several lots together, the result being that different sizes are in one bearing, in which case it is impossible for the bearing to give satisfaction, as the large balls will carry all the weight and consequently be overloaded.

In addition to gauging the balls, they are inspected, for which work

FIG. 14.—SPECIAL BALL GAUGING MACHINES.

girls are employed, as they appear to give better satisfaction, being both quicker and more accurate than boys or men.

The balls as they come from the grinders may contain small defects that are almost invisible, but they are sorted or inspected so that it is almost unknown for a bad ball to remain in the higher grades. There is only a small percentage of bad balls in all that are made. Among the defects are flat spots, which may be due to the stopping of a machine while they are in process of grinding. Occasionally a small defect in the steel will leave a hole that is almost invisible to the naked eye, while other defects are very slight but easily detected. The

culls or refuse balls are used for polishing nickel plated pieces, where they appear to give better satisfaction than buffing and at much lower cost. Fire cracks at one time caused considerable trouble in steel balls, but this defect has been overcome, and for some years such balls have been practically unknown, which is largely due to the fact that different alloys of steel have been experimented with until an article has been produced of great toughness and is least liable to defects of this character.

Description of Various Anti-Friction Bearings.

The various bearings illustrated are used for purposes depending upon the weight to be carried, R.P.M., and the general method of application.

The journal roller bearing (Fig. 15) is fitted with a ball at each end of the rollers, which prevents wear of the cage or retainer, and keeps

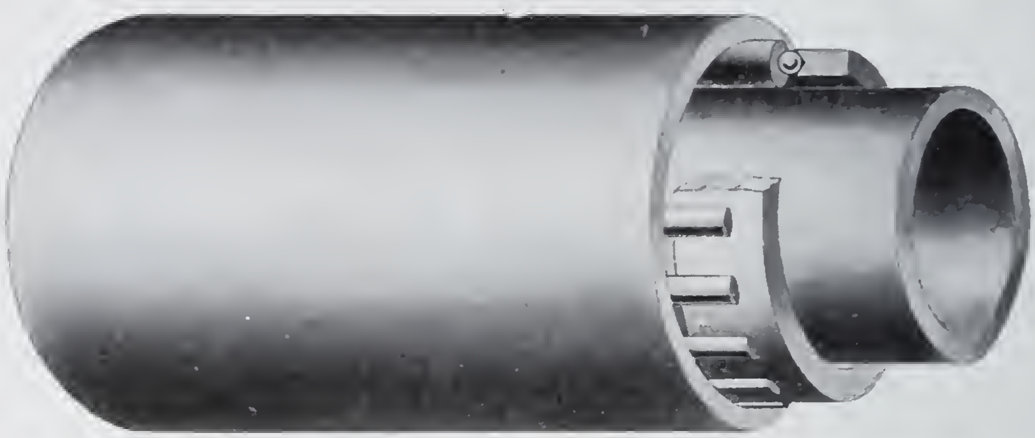


Fig. 15.—Journal Roller Bearing with Ground Casing and Sleeve.

the rollers always in alignment. When properly applied, a sleeve is used to go upon the shaft and a casing over the rollers, both being of steel, hardened and ground, and the rollers being finished in the same manner. Little or no wear should take place provided the proper size rollers are used and that they are oiled or cleaned and applied in proper alignment.

Grooved Ball End Thrust Bearings.

Grooved ball end thrusts of various types are furnished, one with the retainer being used where the speed is high, as it has been found desirable to separate the balls by the use of a cage to prevent crowding of the balls one against the other. Even when the balls have the least variation in size, as above referred to, it is not possible to make the

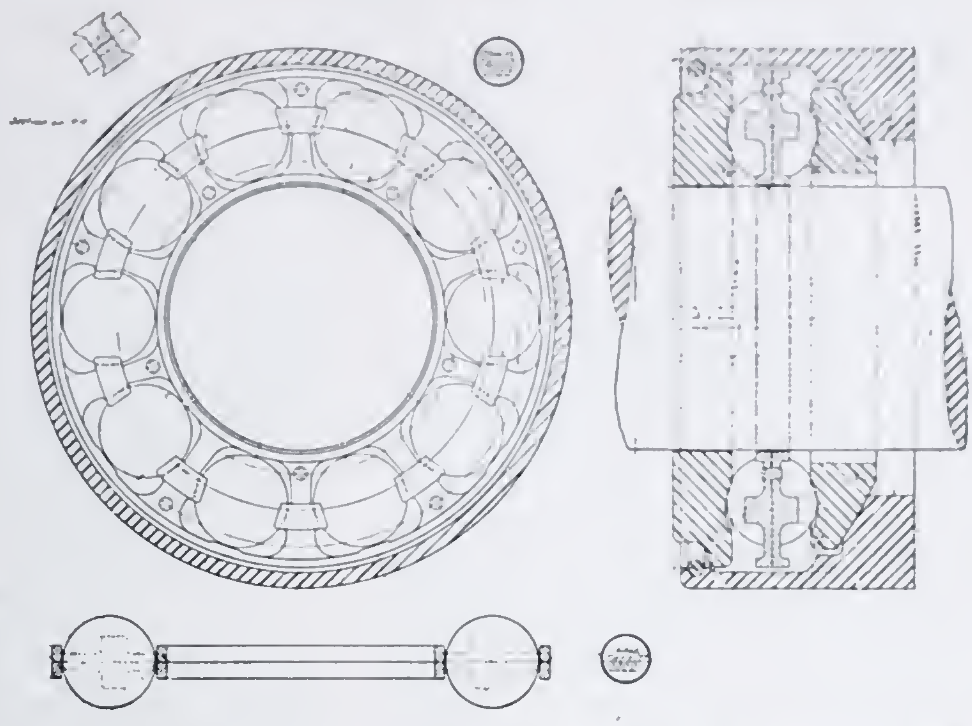


Fig. 16.—Grooved Ball Thrust, Cage, and Leveling Washer.

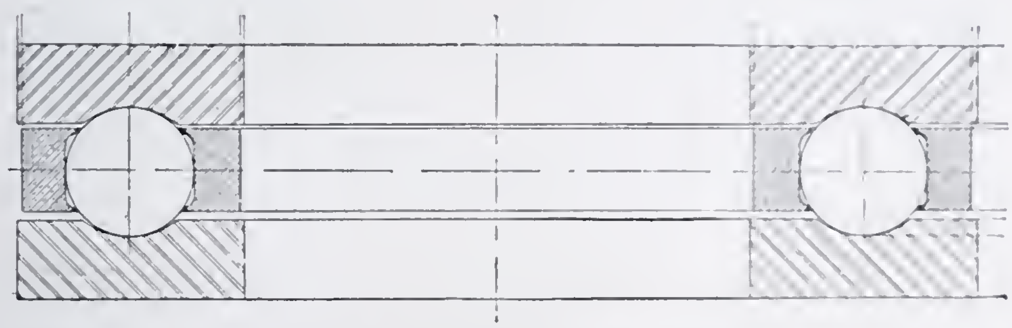


Fig. 17.—Grooved Ball Thrust with Cage or Spacer.

Fig. 18.—Grooved Ball Thrust Collar Bearing.

plates and balls of such a degree of accuracy that crowding will be entirely eliminated.

The roller motor bearing (Fig. 20) has the end of the rollers beveled or chamfered so that they bear upon the cone at one end and the race

FIG. 19.—GROOVED BALL END THRUST.

FIG. 20.—ROLLER MOTOR BEARING.

at the other end, and in this way take up a considerable amount of the end thrust.

Conical or tapered roller bearings for journals (Fig. 21), as distinct

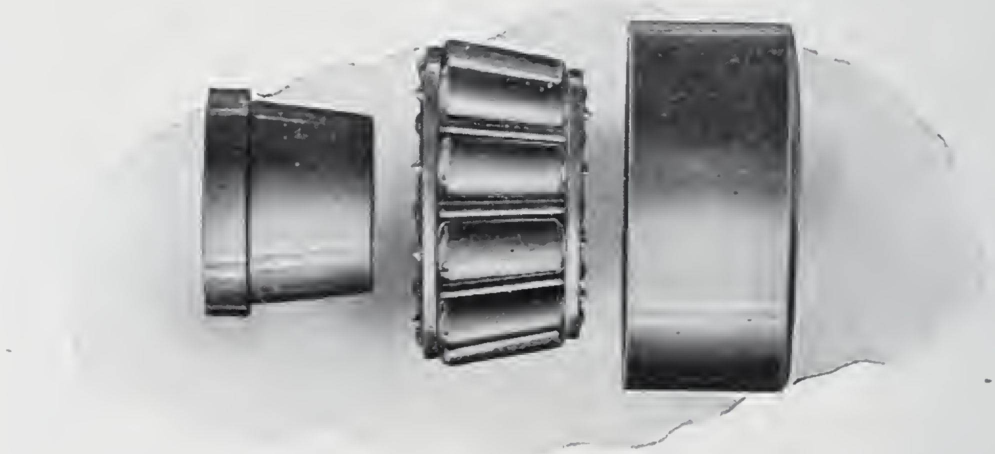


FIG. 21.—TAPERED ROLLER JOURNAL BEARING.

from thrust purposes, have given satisfaction, especially on automobiles, as they permit wear to be taken up.

Various forms of grooved bearings are used, as will be noted in the illustrations. The four-point bearing has been successful on very high speeds, while the three-point and plain two-point bearings are used

extensively. The groove covering a considerable portion of the radius of the ball (Fig. 24), both plates being of this character, or, with one plate grooved and the other plain, has given the best results (Fig. 23).

Ball thrust bearings used on drills, launch propellers, etc., consisting of balls staggered and held in a bronze cage or spacer, with hardened and ground steel washers, have been used more extensively than any

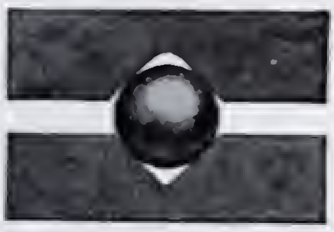


Fig. 22.—Four-point Contact.

Fig. 23.—Single Grooved.

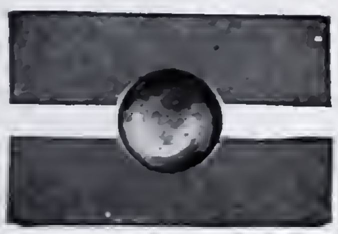


Fig. 24.—Double Grooved.

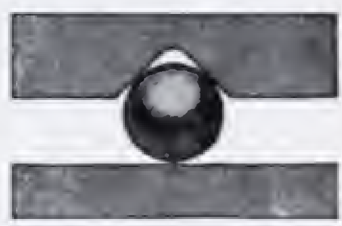


Fig. 25.—Three-point Contact

Figs. 22–25.—Ball Bearings.

other form of anti-friction bearing, several millions being sold during the past few years. They are simple in construction, low in cost, and give very satisfactory results.

The use of a double bearing to take the thrust both ways is desirable in some constructions, and has been used with good success on eleva-

Fig. 26.—Ball Thrust Bearing.

tors, etc. The center washer is made to bear upon a shoulder on the shaft, while the worm takes the side pressure in one direction and a nut or similar device cares for it on the opposite side.

The use of a separate bearing, one at each end of the worm wheel, is a better design from a mechanical standpoint.

In the use of roller bearings it has been found that the best satisfaction cannot be secured unless the parts are of steel, hardened and ground. The sleeves and casings as well as the washers are made on automatic machines, the largest of which takes a bar of stock seven inches in diameter weighing 5000 pounds and works automatically without the assistance of manual labor of any character after the bar is placed in the machine. The parts are then tempered, hardened, or case hardened, according to the work they are to perform and the class of steel used, and are then ground in universal or other grinding machines, while the washers are ground on disc grinders which produce uniform surfaces. Semi-automatic machines are used for cutting the large discs ranging from seven to twelve inches in diameter, which are afterward hardened and ground in the same manner.

A Test with Roller Bearings on a Syracuse Car.

The theoretic saving to be secured by the use of roller or ball bearings has long been fully understood, but the actual benefits derived in prac-

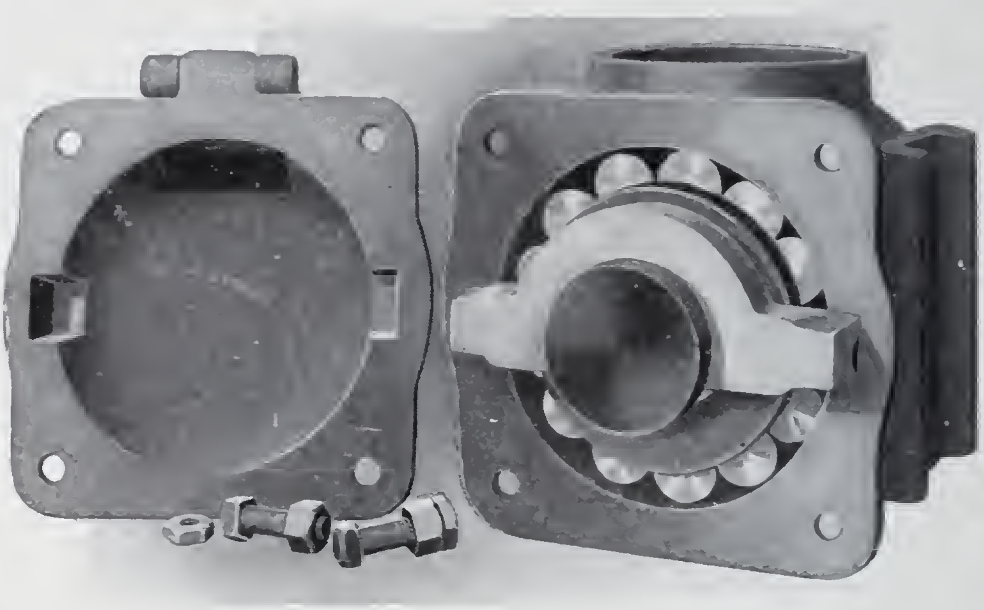


Fig. 27.—Trolley Journal Roller Bearing.

tice are not so well known. Many tests have been made showing their value on machinery, but it is only recently that their use has been fairly tried in electric railway service. Some interesting results are now available regarding tests made on a trolley car in Syracuse, N. Y., for over four and one-half years. The bearing consists of a sleeve of steel which is slipped over and upon the ordinary car axle journal, without changing it in any respect, and upon which the rollers run,

this construction preventing any wear whatever upon the journal. The thrust is cared for in the usual way by a "horseshoe" type of bronze thrust plate, so that no thrust is taken upon the rolls. It is simple in construction and has no parts that require especial attention or care. An oil reservoir is provided into which the rollers run as they revolve around the shaft, and as it uses very little oil, slight attention is required in this respect.

The great saving in power consumption is plainly indicated in the curves shown in Figs. 29 and 30, covering the test run of two cars oper-

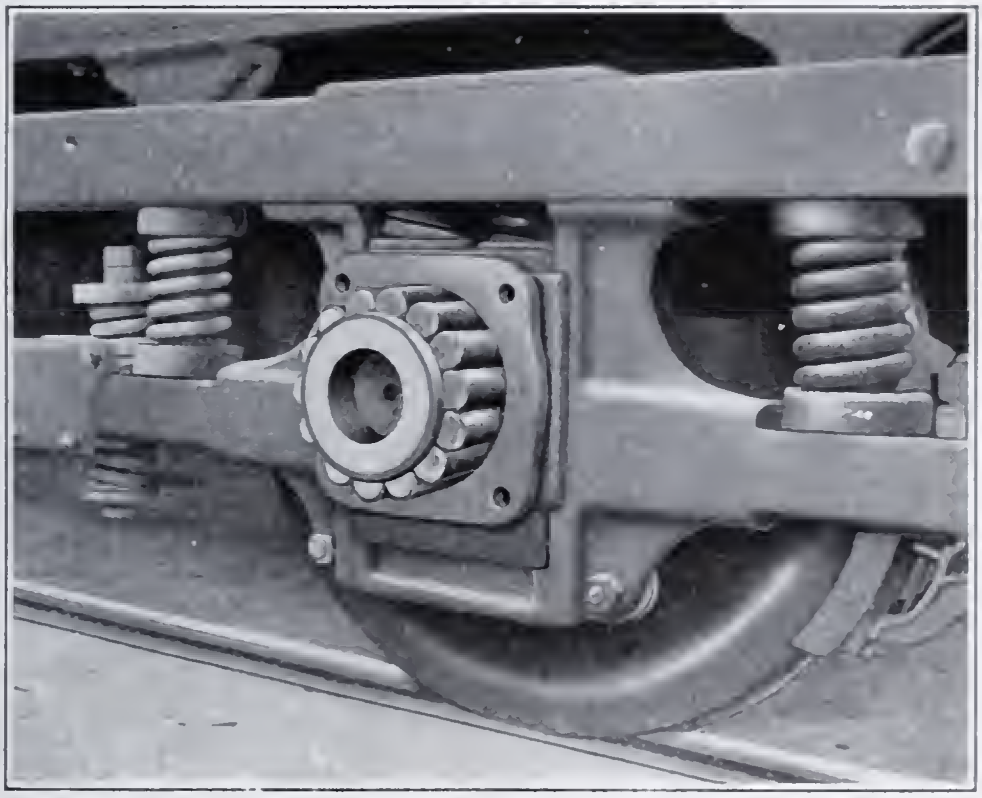


Fig. 28.—Trolley Axle Bearing.

ated under practically the same conditions. The test was made on a three-mile run, which is nearly straight except for one short 90-degree curve. Car No. 70 was equipped with roller bearings, while car No. 87 used the ordinary plain bronze bearings. The amperes and volts applied were measured by calibrated Weston meters, and the power consumed included controller losses. Readings were taken every six seconds.

The time of runs and consumption of energy were as follows:

Car No. 70.

	Time in Minutes.	K. W. Hours.
To Valley	18.1	1.94
Return	16.7	1.16
Total time	34.8	Total energy . . . 3.10

CAR No. 87.

	TIME IN MINUTES.	K. W. HOURS.
To Valley	19.1	4.42
Return	16.1	2.03
Total time	35.2	Total energy . . . 6.45

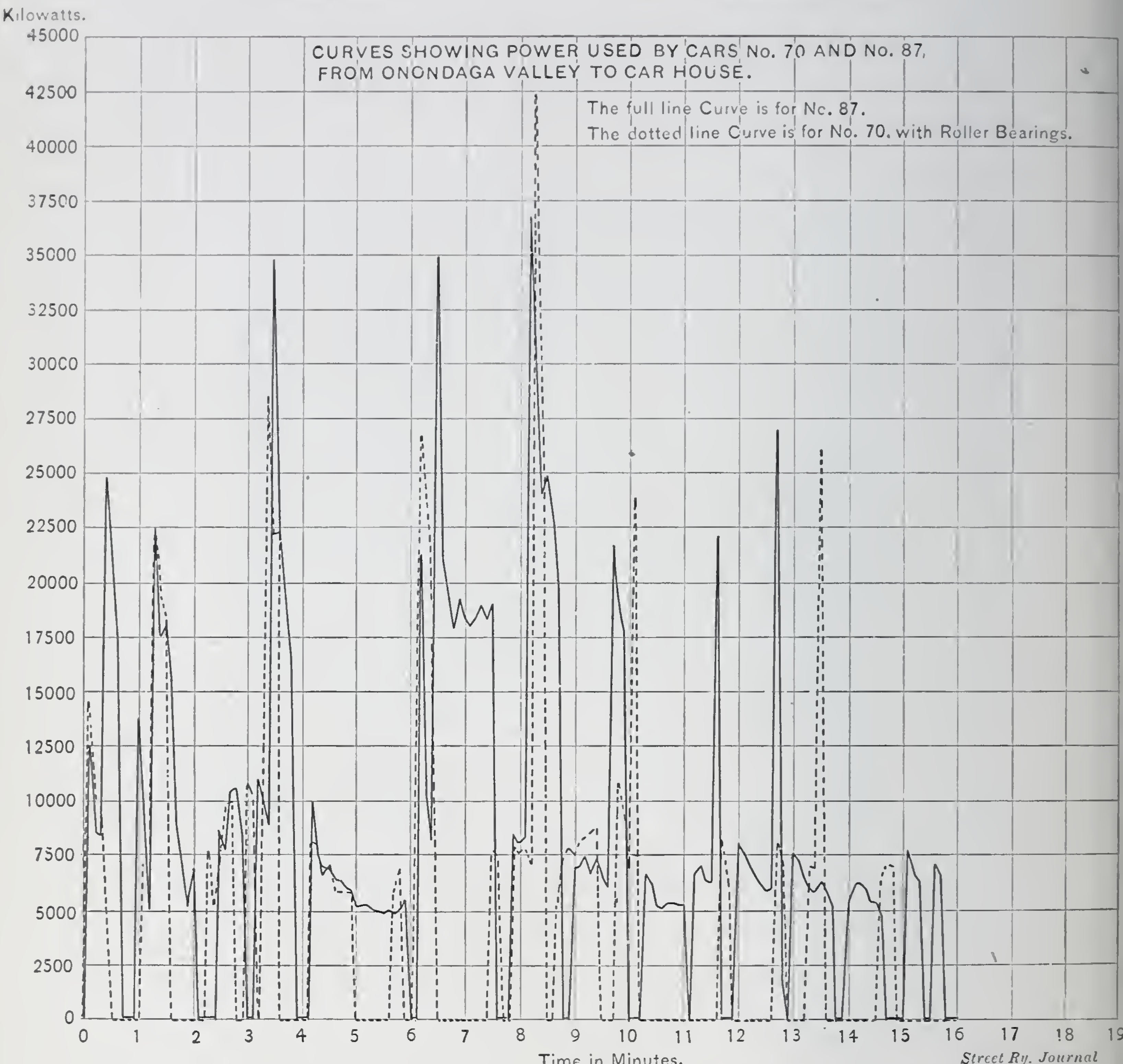


FIG. 29.—TEST RUN WITH PLAIN AND ROLLER BEARING TROLLEY CAR JOURNALS.

The saving secured may seem extraordinary, but is said to be confirmed by further tests in which it has been demonstrated that the net cash saving in coal consumption or its equivalent is $292 per car per annum, in addition to which there is a very considerable saving in the

wear and tear occurring on ordinary brasses. The roller bearings at the end of four and one-half years, and after running 250,000 miles, are in such condition that they may be relied upon to run many years longer. The rolls show an average reduction in diameter or wear of

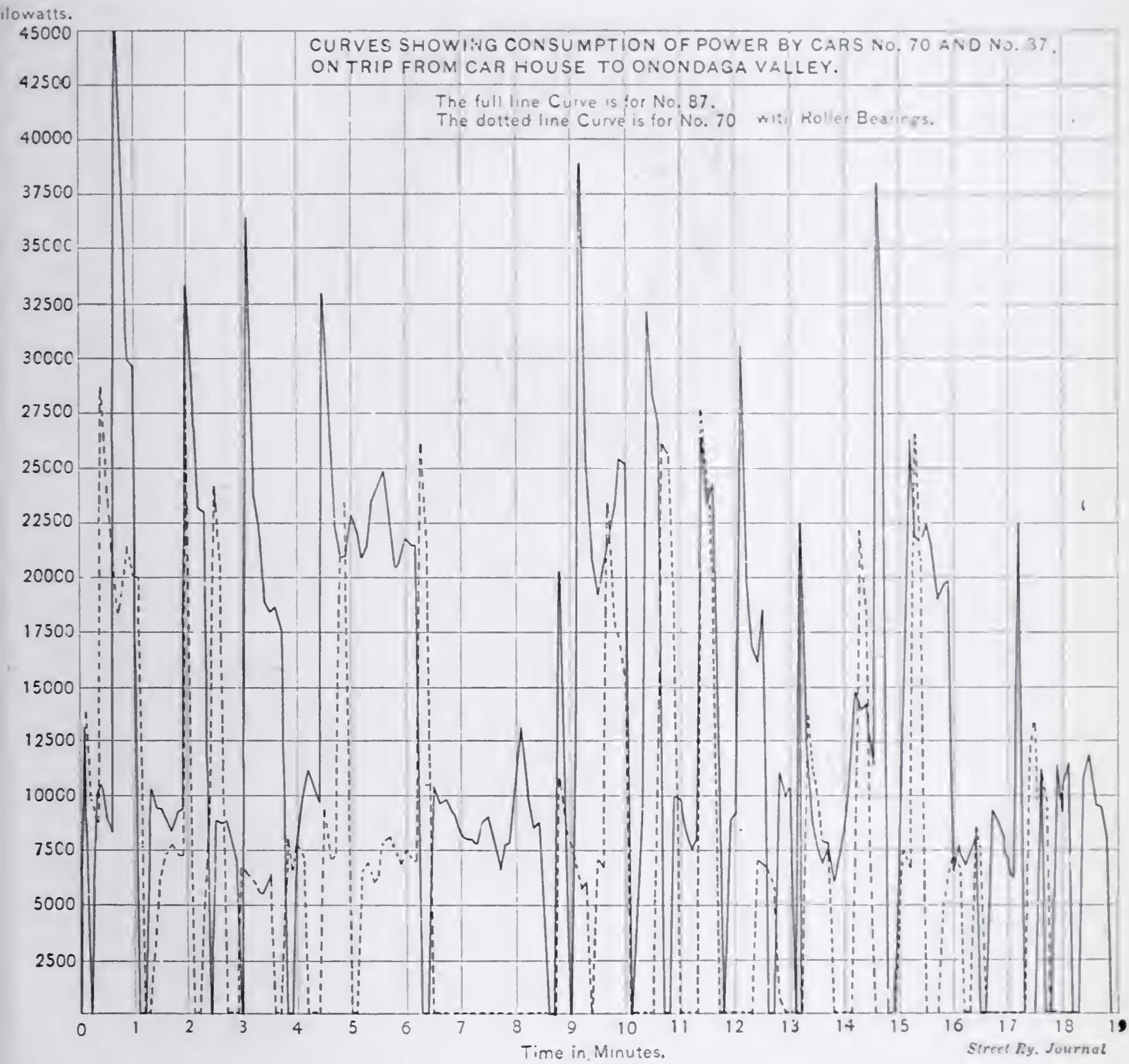


FIG. 30.—TEST RUN WITH PLAIN AND ROLLER BEARING TROLLEY CAR JOURNALS.

.005 to .008 of an inch, and it is evident that with the rollers, axle sleeve, and car box or housing, all properly hardened, as in this construction, very little wear will take place.

The ball and roller bearings referred to above cover but a few forms

of anti-friction bearings which are regularly used in machine constructions. Ball and roller bearings are furnished of many designs, depending upon the work they are to perform, and weighing less than an ounce each and as high as 6000 pounds for one bearing.

Fig. 31.—Annular Ball Bearing.

In addition to the bearings above referred to, there are many designs of journal roller bearings, agricultural type journal roller bearings, self-contained roller bearings, grooved ball shaft bearings, annular ball bearings, and over fifty varieties of shapes and designs not referred to above.

DISCUSSION.

Mr. Quimby.—What pressure per lineal inch on, say, a one-inch roller, is a safe load?

Mr. Eveland.—This is a question I cannot answer, as it depends largely upon many conditions, and especially the class of steel which is used as well as the revolutions per minute at which the bearing is to revolve. I have endeavored to formulate a theory that would be of value, but without success. It is necessary to know exactly the class of work the bearing is to be used for, weight carried, and revolutions per minute, before any intelligent information can be given. A ball bearing is a "point" bearing, while a roller bearing is a "line" bearing. If the load per inch is estimated on the basis of a line bearing, frequently over 10,000 pounds per inch can be figured, which, of course, is impossible from a practical standpoint.

In designing a roller bearing, it is necessary to take into account many points that are not considered with a friction bearing. The size of the shaft and kind of steel used, etc., are of great importance, in addition to the revolutions per minute and weight to be carried. The accuracy with which bearings are finished,

also, has much to do with the weight they will carry. One illustration of how greatly this point is misunderstood by manufacturers is shown in a case which recently came to my notice, in which the user purchased the best balls he could secure and then paid an extra price to have them regauged so as to secure extreme accuracy. He then used them upon washers that were hardened but not ground, and which, therefore, were very inaccurate in finish, varying in diameter from .002 of an inch to .004 of an inch, although the balls did not vary over .0001 of an inch. I suggested the advisability of grinding the plates to correspond with his very accurate balls, but he refused to pay 10 cents each for this work.

Mr. James Christie.—There is a difference of opinion among manufacturers as to the effect of speed on the bearings, some claiming that speed is not a serious factor.

Mr. Eveland.—In my judgment, speed is fully as important as the weight carried. This is not always appreciated by some engineers and manufacturers. One of the latter claims that a quarter-inch ball should not carry weight to exceed 42 pounds to each ball, while the other claims that 1000 pounds for that size ball will give satisfaction. They make no statement regarding the revolutions per minute, or the conditions under which they are used, and it is manifest that one or the other must be incorrect. An average ball of this size will crush under a load of about 6000 pounds.

There appears to be no theory of value that has been worked out, either here or abroad, covering these points, although experiments are now under way that may give some light on this subject. Some German manufacturers have issued considerable literature on this subject in the shape of recommendations as to the size bearing to use under certain conditions, and I have also secured many articles on this subject from foreign technical papers, but I have not found it very reliable, as frequently one contradicts the other, and they also appear to change their views on the subject at frequent intervals.

Mr. Christie.—What is the visible effect of excessive speed when a bearing fails?

Mr. Eveland.—When a bearing begins to wear out, either the balls, rollers, or plates will become roughened and eventually chip off in small flakes or grindings. A bearing used within the limit of its capacity, and made of proper material and workmanship, should last from ten to twenty years without appreciable wear. The rollers in the sample before you have run over 40,000,000 revolutions with a total pressure on the bearing of 3000 pounds, and are in perfect condition and show less than one-quarter of a thousandth of an inch reduction in diameter.

In reply to question asked, no trouble has developed with cages wearing out on the roller thrust bearing. The General Electric Company have used bearings of that character with rollers only $\frac{3}{8}$ of an inch in diameter running 3500 revolutions per minute with a pressure of 1200 pounds, which have shown no evidence of wear after several years' constant operation. We would not have recommended bearings with rollers of that diameter for such high speed, although they have undoubtedly given good satisfaction.

In making these bearings we generally use first a long and then a short roller, reversing the order in the next row or pocket so that the steel plate is entirely covered by the revolving rollers. The cages are generally made from .010 to

.015 of an inch larger than the shaft on which they revolve, and the washers and cages are bushed with bronze for all large sizes.

Mr. Quimby.—Why do roller bearings require oil if they do not wear?

Mr. Eveland.—The rollers being of steel would become rusted, owing to condensation, if from no other cause, and it is therefore necessary to use some lubricant. No ball or roller bearing eliminates all friction, and there are always parts of a bearing which require lubrication, although a very small amount is needed compared to friction bearings. On a propeller shaft, for instance, where seven quarts of oil were used in a given time with the old-style horseshoe type bearing, one quart was required with roller thrust bearings.

Mr. Carl Hering.—How do you determine the difference in the diameters of balls in various directions?

Mr. Eveland.—The balls are gauged by a machine having long steel blades, equivalent to knife-blades, set together a trifle further apart at one end than the other. The balls are then fed automatically upon the two blades, and as they revolve they fall into pockets according to the diameter of the ball. There are various modifications of this design, but they all accomplish the same work so. By gauging balls on machines of this character a number of times, it is possible to secure an extreme degree of accuracy of finish. The best gauged balls do not vary from .0001 of an inch, but it must be remembered that holding a piece of steel in the hand for a short time will heat it to such a degree that expansion will cause a greater variation than this amount.

Mr. Carl Hering.—What do you call extreme accuracy?

Mr. Eveland.—We consider it .0001 part of an inch. The balls are gauged so accurately that a variation of more than this amount is easily detected, not only in diameter with the machine above referred to, but also in sphericity. This latter can be detected by placing the balls in a plate somewhat similar to a child's slate, but made of deadened glass, and by moving it up and down, permitting the balls on it to run around, the rays of light will show broken unless the ball is perfectly round.

Mr. Carl Hering.—Mr. Eveland said, I believe, that there was a great saving of power on trolley cars due to the use of roller bearings. I think he said it took 40 per cent. less power when roller bearings were used. It would be interesting to know more specifically just what he means by this; the statement is somewhat general.

Mr. Eveland.—That was the result of the test I referred to. I know it is probably contrary to what you would figure it in theory, but the test I referred to had been made very carefully, and that is the conclusion reached. We are now conducting experiments along that line, and we will know more about it in about sixty days from now.

Paper No. 1045.

REGULATIONS OF THE BUREAU OF BUILDING INSPECTION IN REGARD TO THE USE OF REINFORCED CONCRETE.

EMILE G. PERROT,
Active Member.

Read November 2, 1907.

At the meeting of the Club on November 4, 1905, President Comfort announced that he had appointed a committee, upon invitation of Edwin Clark, Chief of the Bureau of Building Inspection, to assist him in formulating rules and regulations governing the use of reinforced concrete in the city of Philadelphia.

The members of the committee were Richard C. Develin, Charles Mills, Henry H. Quimby, Walter Loring Webb, and myself, chairman. This committee, in conjunction with Mr. Clark, shortly after appointment, held weekly meetings at the club-house, to which meetings representatives from the Philadelphia Fire Underwriters and Mutual Insurance Companies having local representatives were invited. Mr. Charles A. Hexamer served for the Philadelphia Fire Underwriters, the other insurance companies having no representatives present.

At the meetings of the committee all the phases regarding the design, use, and regulations of reinforced concrete were thoroughly discussed. The laws adopted in the various countries and cities were investigated, and thorough discussions of the requirements took place. The committee, after preliminary work, took no further action in the matter, awaiting the development of the numerous tests that were being made by the U. S. Government and the various testing laboratories connected with the universities throughout the country, with a view to obtaining more light and information for their guidance in drawing up the final rules.

When the unfortunate collapse of the Bridgeman Building, Fifteenth Street below Washington Avenue, took place this summer, the committee realized the importance of taking immediate action regarding the promulgation of definite rules, feeling that as the construction became more general, inexperienced contractors were doing work which heretofore had been in the hands of experts. The following regulations

were the outcome of future deliberations of the committee, whose aim had been to make the rules as simple and as broad in their scope as possible, doing away with all the intricate formulas which it is customary to find in some of the foreign regulations, leaving it to the designer to use whichever formula best suits his training.

All who have read the French regulations will have been amazed with the text-book features of the rules. The Prussian regulations are better than the French, although they give formulas for finding the position of the neutral axis, stresses on the steel, etc. We have purposely omitted these formulas from the regulations, as there are now several text-books which have them thoroughly explained and worked out.

The codification of the rules was based on the building regulations formulated by the National Board of Fire Underwriters and promulgated for adoption by the various cities throughout the United States, making such changes and modifications as our experience and knowledge dictated; it being the intention of the Chief of the Bureau to adopt the form prescribed by the National Board of Fire Underwriters with a view to encouraging uniformity in the regulations throughout the United States.

Some of the important features that it would be well to lay stress on in the new regulations are as follows:

The adoption of a 1–2–4 mixture of concrete throughout, instead of the proportion of 1–2½–5, as had been in use heretofore. The reason of establishing this proportion was the fact that the result of tests on full-size columns at the Watertown Arsenal in the years 1905 and 1906 and test made by Professor Talbot at the University of Illinois showed a much lower carrying capacity for a lean mixture of concrete than had been anticipated, in fact, with the allowable unit stress at 500 pounds, a column with a 1–3–6 mixture would not have a factor of safety of four, as the ultimate strength on the specimens tested by the Government only averaged 1524 pounds per square inch. But with a 1–2–4 mixture the strength of the column is increased approximately 50 per cent., so that a value of 500 pounds per square inch on the column gives a factor of safety of more than four, the ultimate strength averaging 2288 pounds.

It may be said, why not make the columns a 1–2–4 mixture and the floors 1–2½–5, or 1–3–6 mixture? Any one who has attempted to do it knows the difficulty of getting a column of 1–2–4 concrete continuous from the footings to the roof beams. The section of the floor connecting with the columns will necessarily have to be cast separately, and if

a different mixture is used in the floor, when the beams and slabs are cast the concrete will flow into the column form, as it is necessary to stop the column, when casting it, at the bottom of the beam and allow it to settle before filling the beams. This will result in having a 1–2–4 mixture in the shaft of the column and a 1–2½–5 mixture at the floor level, so the column is no stronger than if it was a 1–2½–5 mixture throughout, which is the condition we desire to avoid. The action of the frost on the concrete was taken into consideration, and it was decided that a 1–2–4 mixture used in freezing weather would have a larger margin of safety for beams and floor slabs than 1–2½–5 or 1–3–6.

The use of none but the best Portland cement, which would pass the accelerated test and meet the requirements as to tensile strength, was deemed of great moment; an average of the tensile strength recommended by the American Society of Testing Materials being adopted. The accelerated test is a little more severe than those requirements, it being considered more important to have a sound cement than one very high in tensile strength, as the future of the building would be endangered by the use of unsound cement. The requirement of filing a report with the Bureau of the test on each carload of cement was adopted as being the best means of insuring the use of none but the proper quality of cement.

A change from the values heretofore in use by the Philadelphia Bureau for the ratio between the moduli of elasticity of steel to concrete and the safe unit stresses on the concrete was made. After investigation, it was found that the modulus of elasticity of concrete determined by experiment is about 2,500,000 pounds, and it was decided that a value for the ratio of the moduli of elasticity of concrete to steel for stone or gravel concrete should be one to twelve instead of one to twenty, and a corresponding change in the allowable compression stress of the concrete in cross-bending from 500 to 600 would bring the results practically the same as the Bureau had been using. It was not the intention to change from the standard already adopted in regard to the effective strength of the beam, but simply to get the values more in accordance with what later experiments had shown to be the real values for the two materials, the strength of the composite beam being in no way changed.

Further, the safe tensile stress on the steel was maintained at 16,000 pounds, no greater stress being allowed on high elastic limit steel. While the committee felt that a stronger beam resulted from the use of high elastic limit steel, it was found to be impracticable for the build-

ing department as now constituted to be able to maintain uniformity in the product, there being various makes of steel on the market, any one of which could be substituted for the other without the knowledge of the building department, and in the interest of public welfare it was deemed advisable not to make any additional allowance of strength on the high elastic limit steel.

TABLE I.

*For Calculating Moments of Resistance of Rectangular Beams Made of Stone or Gravel Concrete. Based on the Concrete as the Limiting Factor.**

P	x	K
.0050	0.294	72
.0058	0.31	83.4
.0060	0.314	84.3
.0070	0.334	89.0
.0080	0.352	93.2
.0090	0.368	96.8
.0100	0.384	100.4
.0110	0.398	103.5
.0120	0.413	106.9
.0130	0.422	108.9
.0140	0.438	111.8
.0150	0.447	114.1

M_r = resisting moment in inch pounds.
x = ratio of depth of neutral axis to depth of steel.
c = unit stress in concrete.
S = unit stress in steel.
A = area of steel.
b = breadth of beam.
d = distance from top of concrete to center of action of steel.
g = thickness of slab.
l = length of span in feet.
p = ratio of steel area to area of concrete above steel.
w = load in pounds per running foot.
r = ratio of the coefficient of elasticity of steel to that of concrete.

$$M_r = Kbd^2 \tag{1}$$

$$x = 12p\left(\sqrt{1 + \frac{1}{6p}} - 1\right) \tag{2}$$

$$K = \frac{cx}{2}\left(1 - \frac{x}{3}\right) \text{ based on concrete.} \tag{3}$$

$$K = P\,S\left(1 - \frac{x}{3}\right) \text{ based on steel.} \tag{4}$$

$$P\,S = \frac{cx}{2} \tag{5}$$

$$w = \frac{Kbd^2}{1.5\,l^2} \text{ or } K = \frac{1.5wl^2}{bd^2} \tag{6}$$

Example: To find the size of rods required in a 4-inch slab spanning 6 feet to carry 190 pounds per square foot total load, use formula 6,

$$K = \frac{1.5wl^2}{bd^2} = \frac{1.5 \times 190 \times 6^2}{12 \times 3^2}$$

$$K = \frac{10260}{108} = 95$$

*The value of K when P = .005 is based on the tension in the steel, as below the ratio .0058 the steel is the limiting factor.

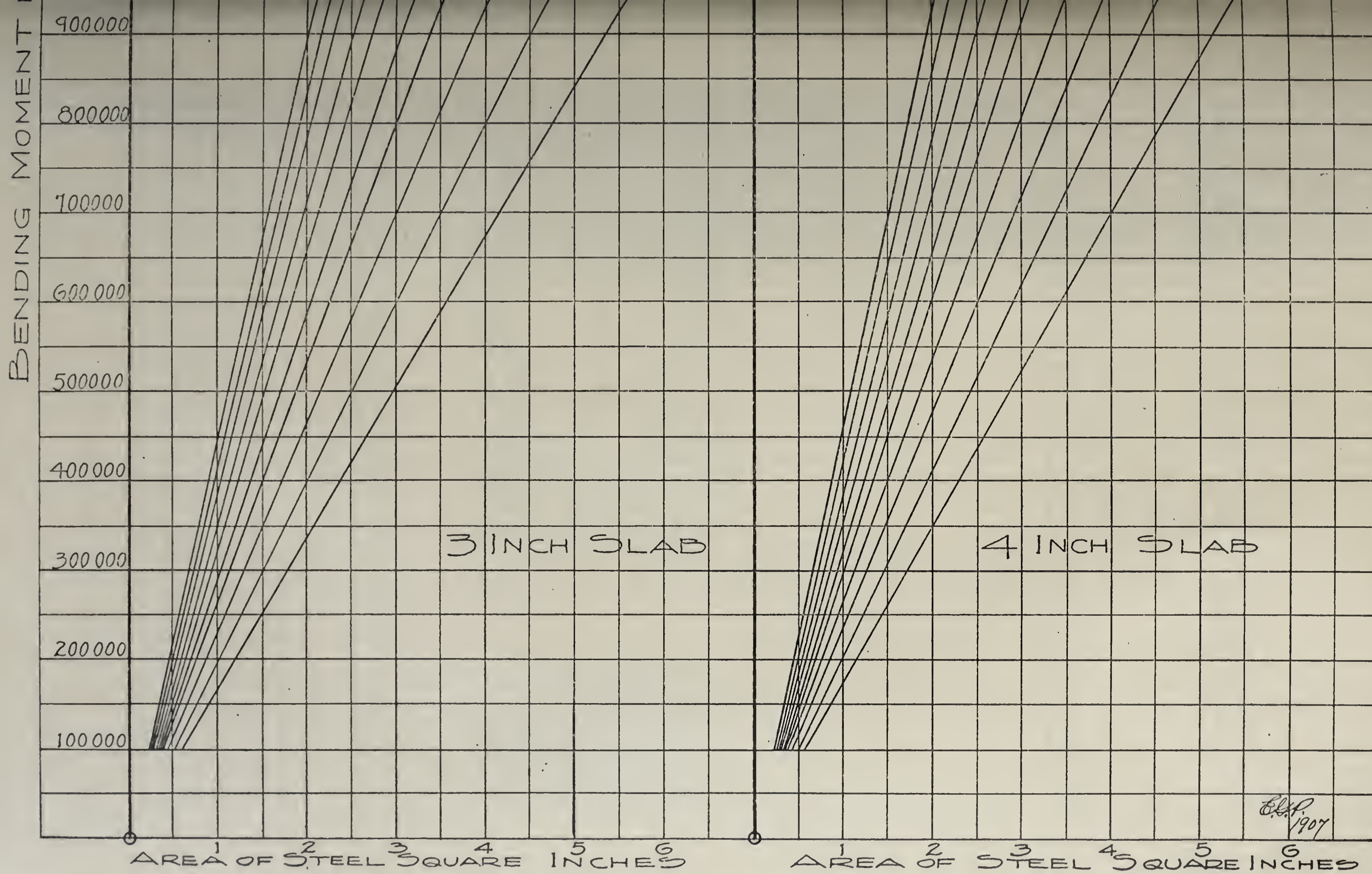
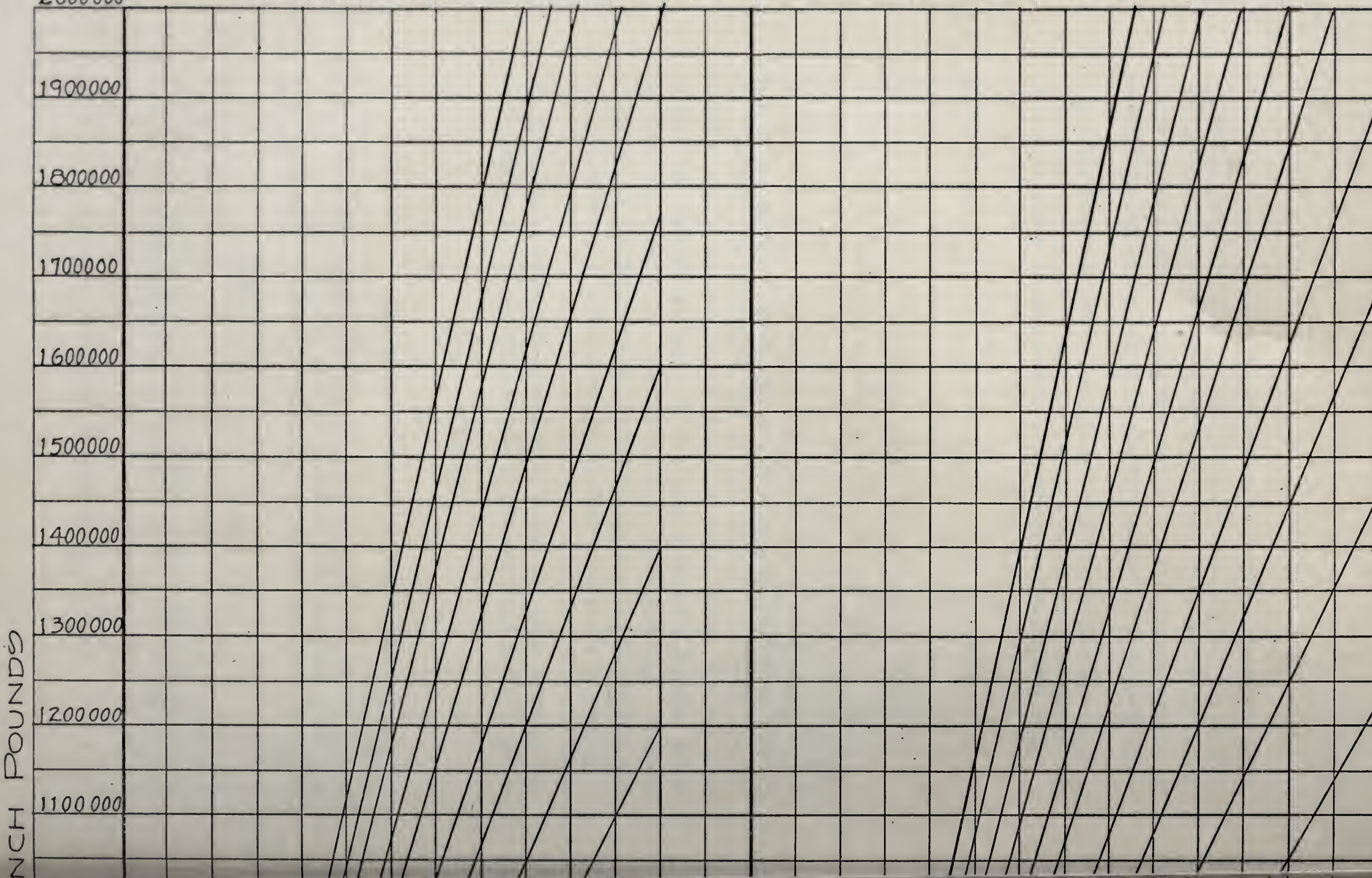

BENDING MOMENT
900000
800000
700000
600 000
500000
400 000
300 000
200 000
100 000
3 INCH SLAB
4 INCH SLAB
1
2
3
4
5
6
AREA OF STEEL SQUARE INCHES
1
2
3
4
5
6
AREA OF STEEL SQUARE INCHES
1907

PLATE 1.

DIAGRAM OF THE STRENGTH OF TEE BEAMS



Look in Table I under column "K" for number nearest 95, and on a line opposite 96.8 under "P" is the percentage of steel per running foot in the slab, in this case being .009. Then multiply the area of concrete above the rods for a distance of 12 inches by this percentage, and the answer equals the area of steel.

Thus: $12 \times 3 \quad = 36$ square inches.
$36 \times .009 = .324$ square inches.

spacing the rods 4 inches c to c $= .108$ square inches each. The nearest size to this area is $\frac{3}{8}$ inch round bar, which has an area of .11 square inches.

Note.—3 inches is used for depth of slab, as the depth is taken to center of action of steel.

Formula to find the area of the steel in TEE BEAMS:

$$A = \frac{M}{16000\left(d - \frac{g}{2}\right)} \qquad (7)$$

which is the bending moment in inch pounds divided by 16,000 times the distance from the center of the slab to the center of action of the steel.

Plates 1, 2, and 3 show diagrams of the strength of Tee beams of various depths and for four thicknesses of slabs worked out by the above formula. The application of the diagram is very simple; for example, if the bending moment is found to be 1,000,000 pounds, the area of steel for any depth beam is found on the bottom of the diagram directly under the intersection of the horizontal line opposite the bending moment and oblique line of the depth of beam taken, the depth of the beam being the vertical dimension of the rib below the slab.

MODULUS FIGURES FOR TEE BEAMS.

Formula: $$W = \frac{r \times \text{Area Steel}}{g} \times \frac{Yt}{Yc} \qquad (8)$$

$$x = \frac{1}{1 + \frac{S}{cr}} \qquad (9)$$

$$x = .31$$

W = Width of slab in compression to balance the area of steel in the rods. The dimensions of the figures in Plate 4 were derived from the above formula.

Note.—The spacing of the beams should never be closer than the distance "W."

The making of reinforced concrete walls two-thirds the thickness of brick walls seems to the committee to be the only course consistent with the legitimate use of the material, as the tensional value given the concrete by the use of reinforcing metal is wholly lacking in brick masonry, hence the greater stability of the reinforced concrete walls.

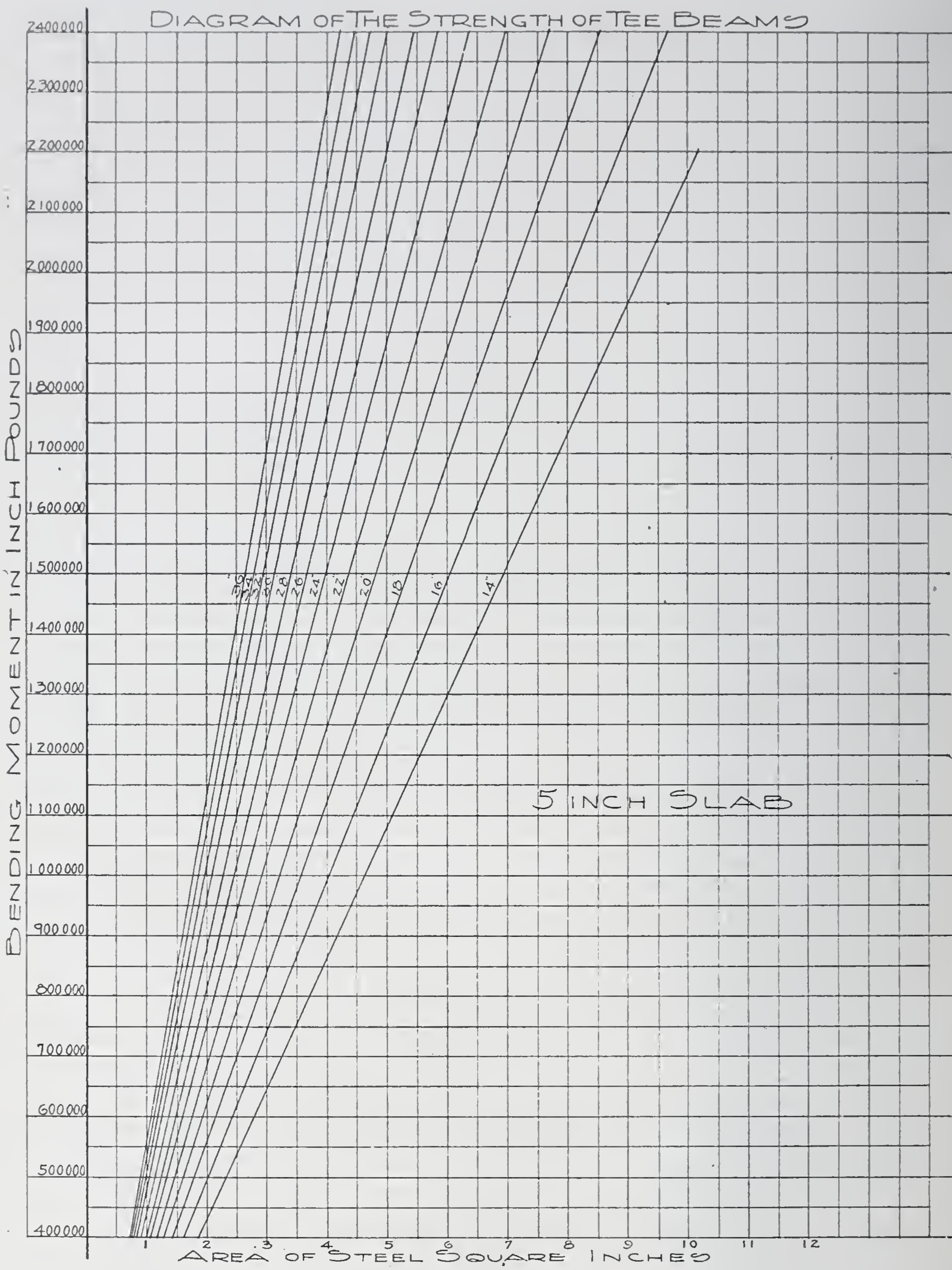


DIAGRAM OF THE STRENGTH OF TEE BEAMS
2400000
2300000
2200000
2100000
2000000
1900000
1800000
1700000
1600000
1500000
1400000
1300000
1200000
1100000
1000000
900000
800000
700000
600000
500000
400000
BENDING MOMENT IN INCH POUNDS
1 2 3 4 5 6 7 8 9 10 11 12
AREA OF STEEL SQUARE INCHES
5 INCH SLAB
36 34 32 30 28 26 24 22 20 18 16 14

PLATE 2.

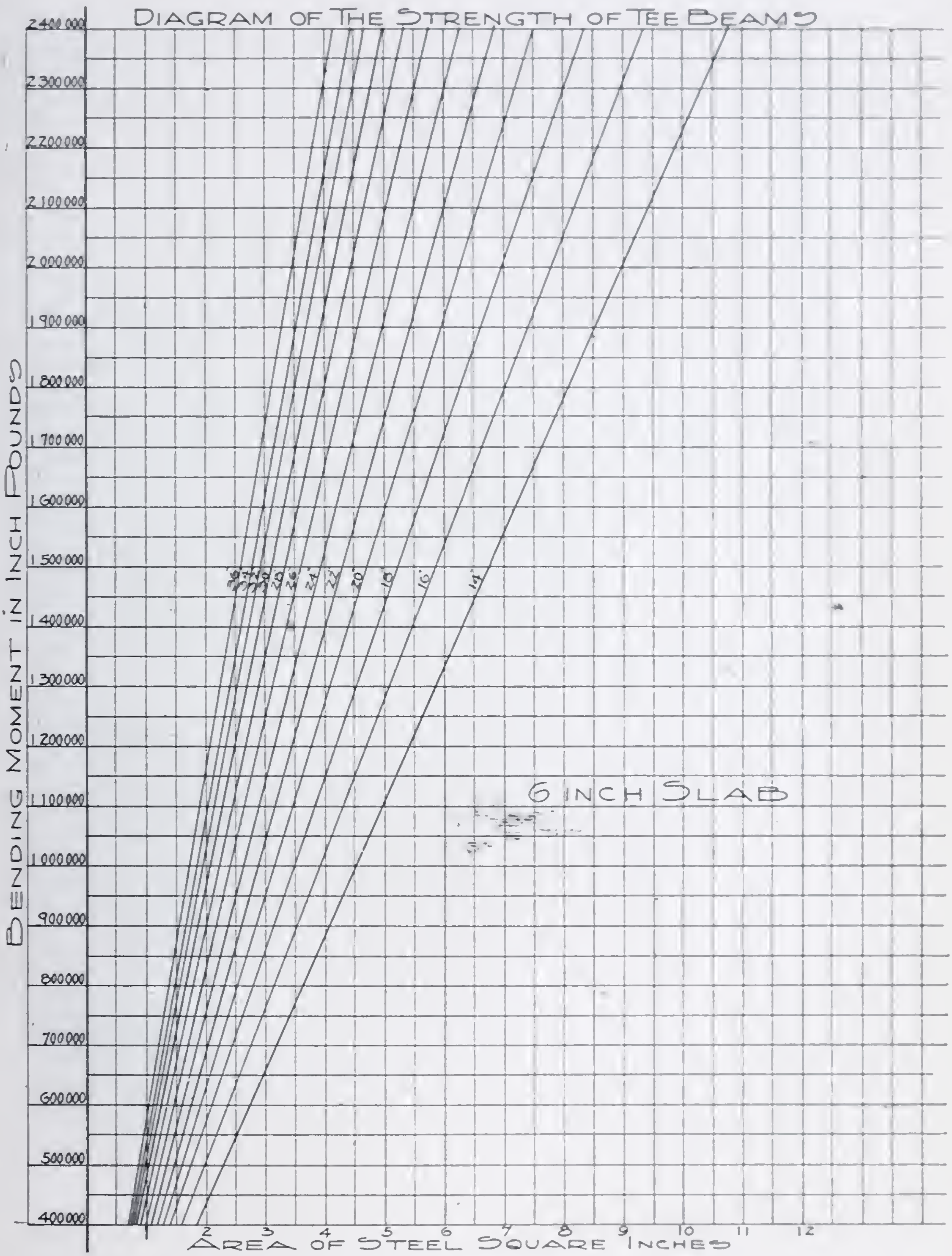


DIAGRAM OF THE STRENGTH OF TEE BEAMS
BENDING MOMENT IN INCH POUNDS
2400000
2300000
2200000
2100000
2000000
1900000
1800000
1700000
1600000
1500000
1400000
1300000
1200000
1100000
1000000
900000
800000
700000
600000
500000
400000
6 INCH SLAB
14
16
18
20
22
24
26
AREA OF STEEL SQUARE INCHES
1 2 3 4 5 6 7 8 9 10 11 12

PLATE 3.

The compulsory use of stirrups throughout the length of the beams when the floor slab is figured as part of the beam is deemed of the greatest importance, as experience has fully demonstrated that it is unwise to count upon the monolithic character of a Tee beam unless a mechanical tie or bond is introduced between the slab and the stem or beam extending throughout the length of the beams; these stirrups or

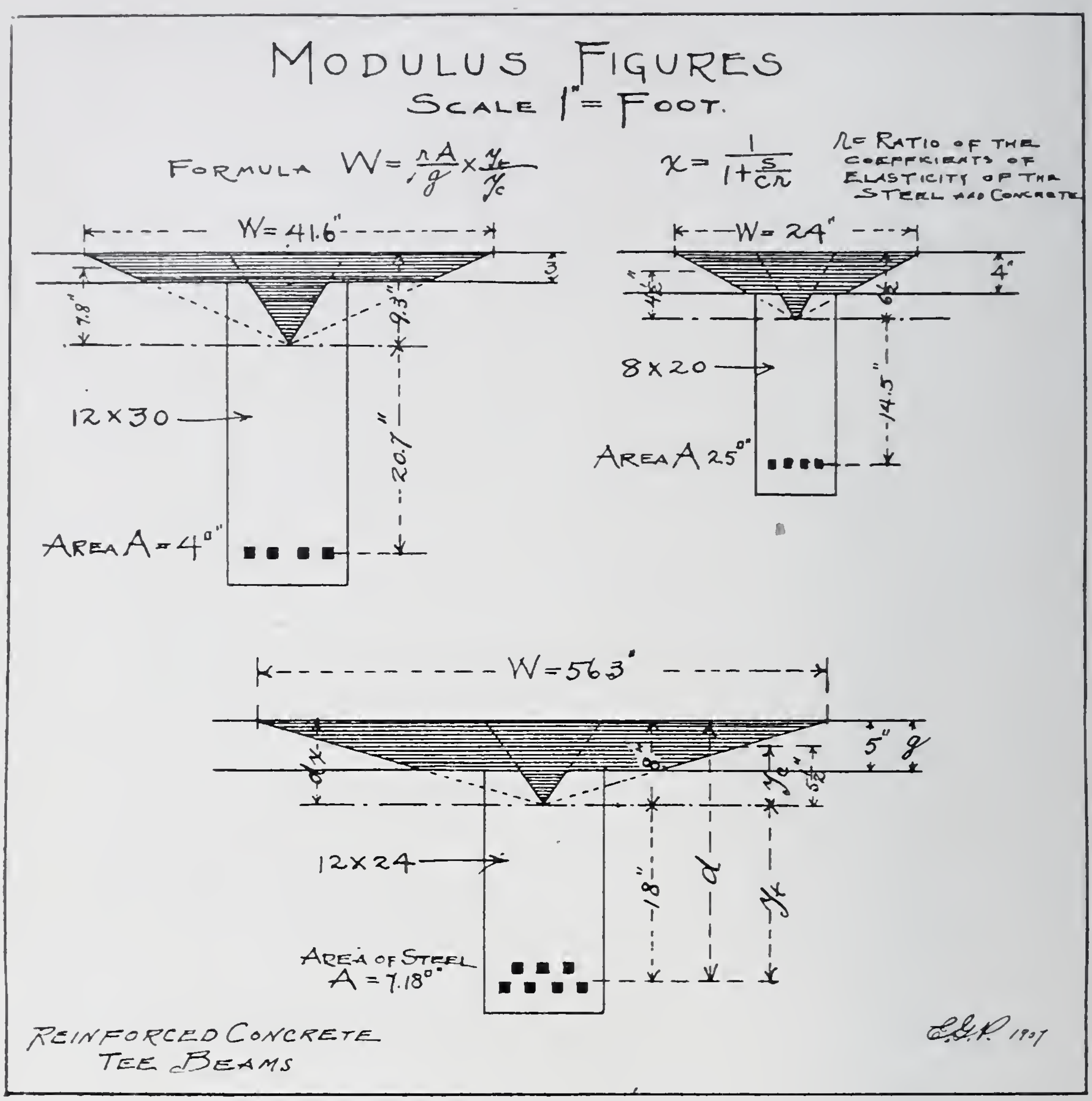


PLATE 4.

ties being used notwithstanding calculation, show the width of the beam to be found sufficient to safely resist the horizontal shear between the slab and the stem, examples of floors in which the slab has parted from the beam are frequent, and the free use of stirrups in these floors is what prevents failure from shear. I have in mind a floor in a building in this city which is carrying a 100-ton machine. One of the beams

under it is cracked horizontally at the junction with the slab, but is restrained from separating by the stirrup. This crack occurred before

PLATE 5.—REINFORCEMENT FOR HOOPED COLUMNS, VICTOR TALKING MACHINE CO.'S BUILDING.

any load was placed on the beam, being due to shrinkage, the machine in question not being placed on the floor for over a year after the building was completed. Records showed that after the machine was placed

no further separation took place, the stirrups doing the work they were intended to do. Another instance of the reverse order was the failure of a girder due to shear between slab and stem, which, in the writer's opinion, could have been prevented by the free use of stirrups, extending up into the slab along the entire length of the beams.

The adoption of a higher unit stress on hooped columns over those with longitudinal reinforcement only was determined from the result of experiments on full-size columns, tested at the Watertown Arsenal during the year 1905 and 1906. These tests conclusively show the great value of hooping concrete, the ultimate unit stress on one being as great as 5289 pounds per square inch. This was a 1–2–4 mixture without longitudinal rods.

While Monsieur Considère, the celebrated French engineer, was the first one to deduce a practicable working formula for hooped columns, the writer thinks that a more rational formula than his could be devised which would approximate as closely to working conditions as column formulas now in use for the design of columns in other materials than concrete. I have prepared a formula for hooped columns, an exposition of which I made in the discussion of Mr. Perring's paper, delivered before this Club last year. For the benefit of those, however, who would like to have the formula explained, I have introduced it here a second time.

FORMULA FOR HOOPED COLUMNS.

$$S = \text{Stress in one Hoop} = .215 \times 1000 \times \frac{d}{2} \times U \qquad (10)$$

In which U equals spacing of hoops.
d " diameter of column to center of hoops.

The photograph of the reinforcement for a hooped column shown in Plate 5 illustrates the principle of building up a column reinforcement as a unit ready to place in the mould; the hooping of these columns consisted of a wire cable in the form of a helix, the size of the cable being determined by the formula given above.

The reduction of the unit stress on columns over fifteen diameters in length was considered advisable, as the danger of constructing long thin columns was very evident from the failure at the Bridgeman Building. I give a formula for finding the reduction of the unit stress: this is Gordon's formula with a constant worked out to suit concrete.

COLUMN FORMULA.

Basic formula (Gordon's):

$$C = \frac{W}{A}\left(1 + \frac{Afd}{5EZ} \times \frac{l^2}{d^2}\right) \qquad (11)$$

$$C = P\left(1 + a\frac{l^2}{a^2}\right) \text{ or } P = \frac{C}{1 + a\frac{l^2}{d^2}} \qquad (12)$$

$$a = \frac{Afd}{5EZ} = .0005 \qquad (13)$$

C = Allowable unit stress on short columns.
P = Reduced unit stress to be used when column exceeds 15 diameters.
W = Load on column in pounds.
A = Area of column in square inches.
f = Stress on concrete at elastic limit.
d = Length of side of column.
E = Coefficient of elasticity of concrete.
Z = Section modulus.
l = Length of column in inches.
d = Least side in inches.

Example: What is the allowable unit stress on a column 12 inches square 20 feet long? Use formula 12.

$$P = \frac{C}{1 + a\frac{l^2}{d^2}}$$

$$P = \frac{500}{1 + .0005\frac{240^2}{12^2}} = \frac{500}{1.2} = 416 \text{ lbs.}$$

FORMULA FOR ECCENTRIC LOADING ON SHORT COLUMNS.

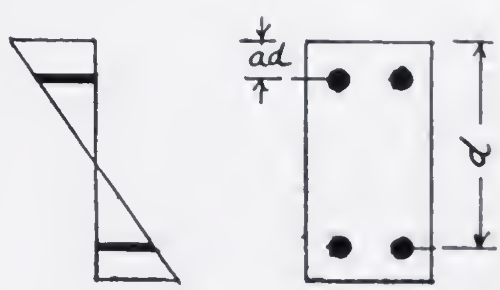
$$P = \text{Max. Stress} = W\left(\frac{1}{A} + \frac{X}{Z}\right) \text{ or } \frac{W}{A} + \frac{WX}{Z} \qquad (14)$$

In which X = eccentricity in inches.

DOUBLE REINFORCED CONCRETE RECTANGULAR BEAMS.

$$S^1 = cr\frac{x - a}{x} \qquad (15)$$

S^1 = Stress in steel at top
a = Ratio of depth d to depth ad
P = Ratio of steel in bottom
P^1 = Ratio of steel in top



$$x = \sqrt{2r(P + P^1a) + r^2(P + P^1)^2} - r(P + P^1) \qquad (16)$$

$$\frac{M}{bd^2} = \left[SP(1 - a) - \frac{cx}{2}\left(\frac{x}{3} - a\right)\right] \qquad (17)$$

$$\frac{cx}{2} + P^1S^1 = PS \text{ or } c = \frac{PS - P^1S^1}{\frac{x}{2}} \qquad (18)$$

Short formula for double reinforced beams:

$$M = S(d-ad) \tag{19}$$

This formula checks up very closely with the more exact formula, and may be used with perfect safety in its place. The area of the steel in the top and bottom of the beam are considered as being equal.

Note.—Formulas 15, 16, 17, and 18 are taken from Taylor and Thompson's book on "Plain and Reinforced Concrete," and the reader is referred thereto for a full explanation of them.

The use of reinforced concrete for very heavy cantilevers supporting a party wall ten stories high is shown in Plate 6, which gives the dimensions of the concrete and steel, the load on the first-story columns, supported on the cantilever, is 385,000 pounds. The building has now reached the level of the ninth floor, as shown in Plate 7, which is a photograph of the concrete cage.

Plate 8 is a view of smaller cantilever beams supporting the rear wall and floor, but of longer projection, the center of the wall being seven feet from the center of the column; a cantilever in this case exists at each story, whereas in the other case one cantilever carries the wall the entire height as well as supporting ten floors and a roof.

Below is given the text of the new regulations as adopted by the committee and now in force in the city. The formulas given above do not represent the work of the committee, but are put forth by the author to give easy working formulas that will agree with the new regulations.

Regulations.

The term "reinforced concrete" shall be understood to mean an approved concrete mixture reinforced by steel or iron of any shape, so that the steel or iron will take up all the tensional stresses and assist in the resistance to compression and shear.

Before a permit to erect any reinforced concrete structure is issued, complete specifications and drawings shall be filed with the Bureau of Building Inspection, showing all details of the construction, size and position of all reinforcing rods, stirrups, etc., and giving the composition and proportions of the concrete.

The execution of the work shall be performed by workmen under the direct supervision of a competent foreman or superintendent.

Reinforced concrete construction will be accepted for fireproof buildings of the first class, if designed as hereinafter prescribed; provided, that the aggregate for such concrete shall be clean, broken,

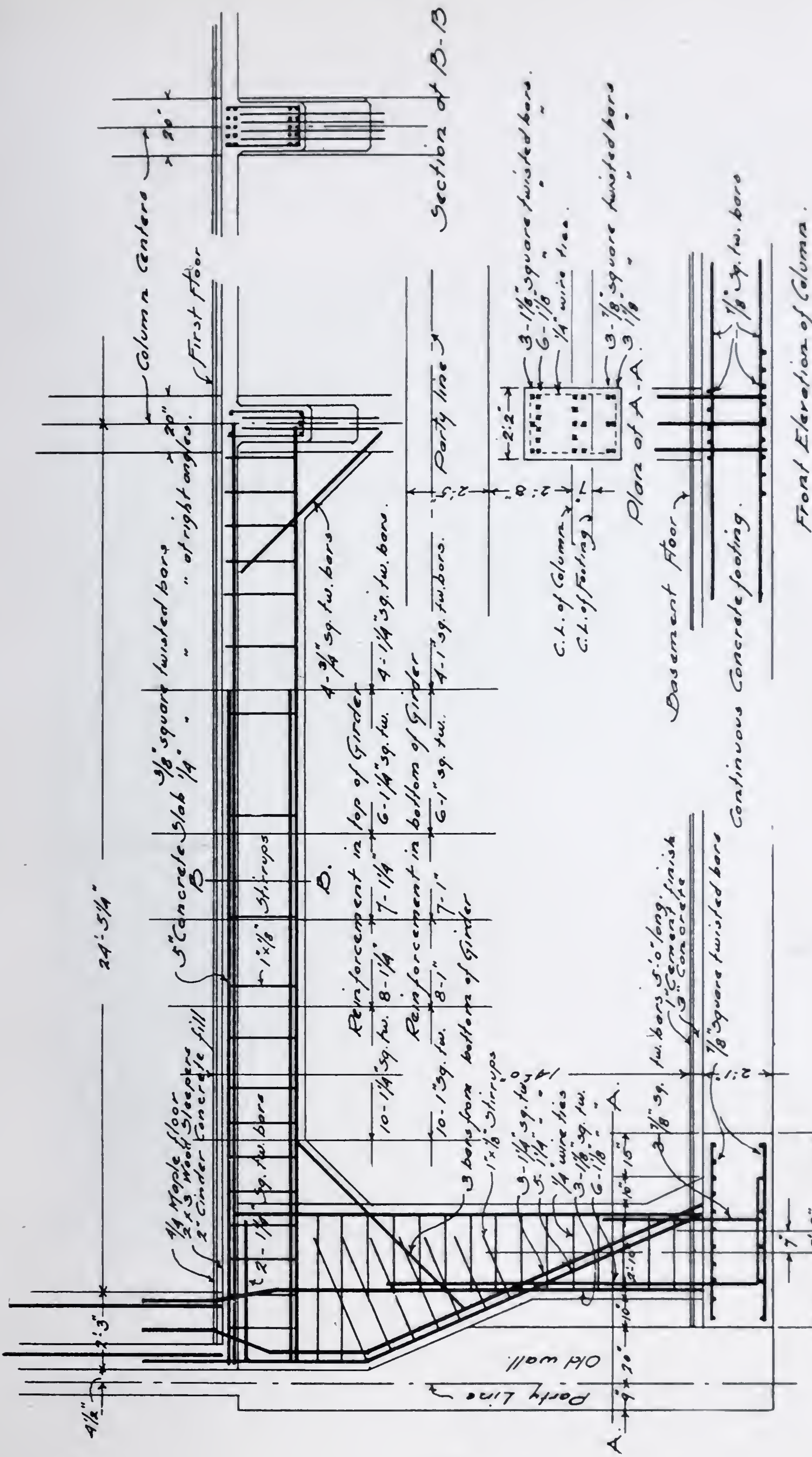


PLATE 6.—REINFORCED CONCRETE CANTILEVER, BOYERTOWN BUILDING.

hard stone, or clean graded gravel, together with clean siliceous sand or fine grained gravel; should the concrete be used for flooring between

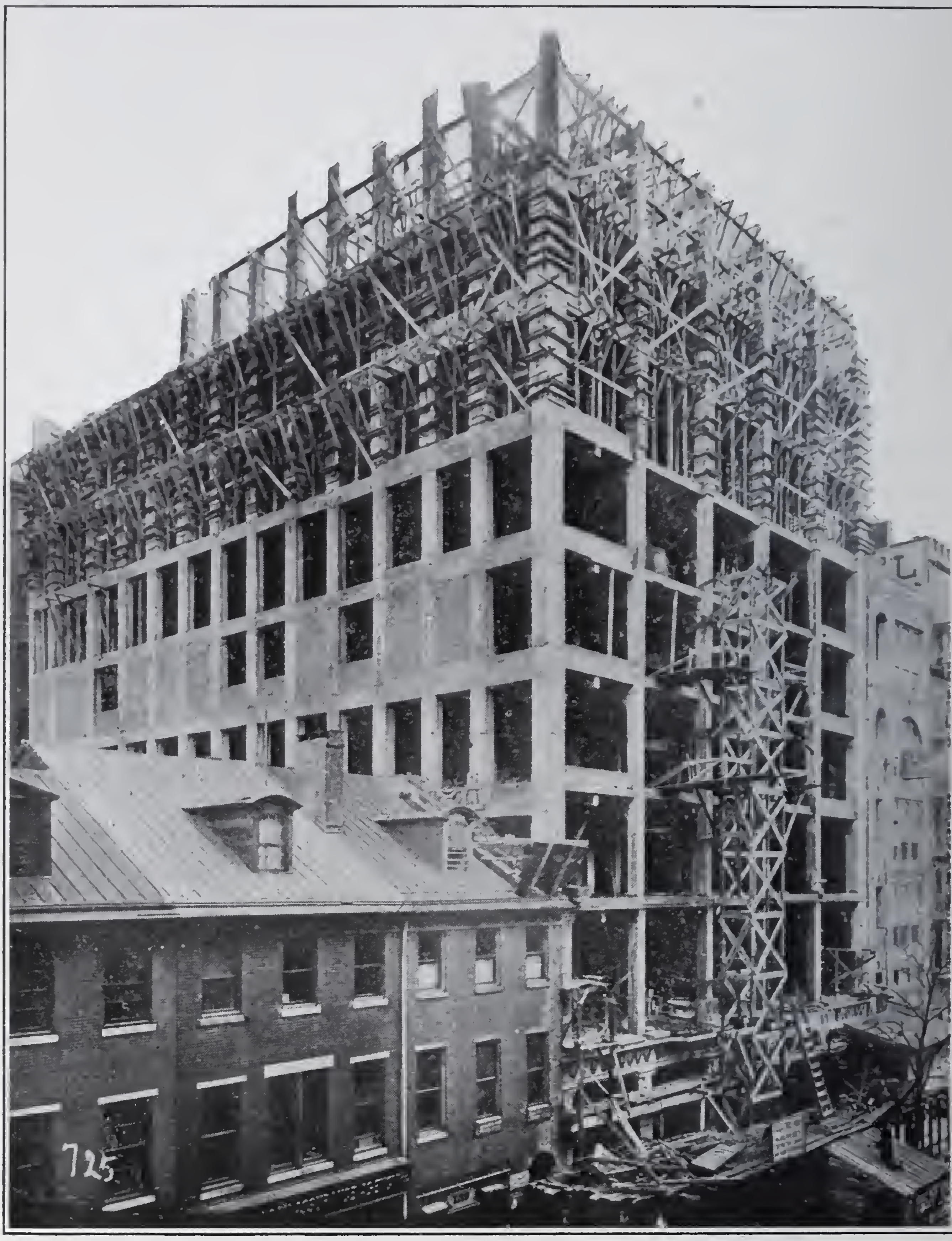


Plate 7.—Reinforced Concrete Skeleton Construction, Boyertown Building.

rolled steel beams, clean furnace clinkers entirely free of combustible matter, or suitable seasoned furnace slag may be used; when stone

is used with sand or gravel it must be of a size to pass through a one inch ring, and 25 per cent. of the whole must not be more than one-half the maximum size; and provided, further, that the minimum

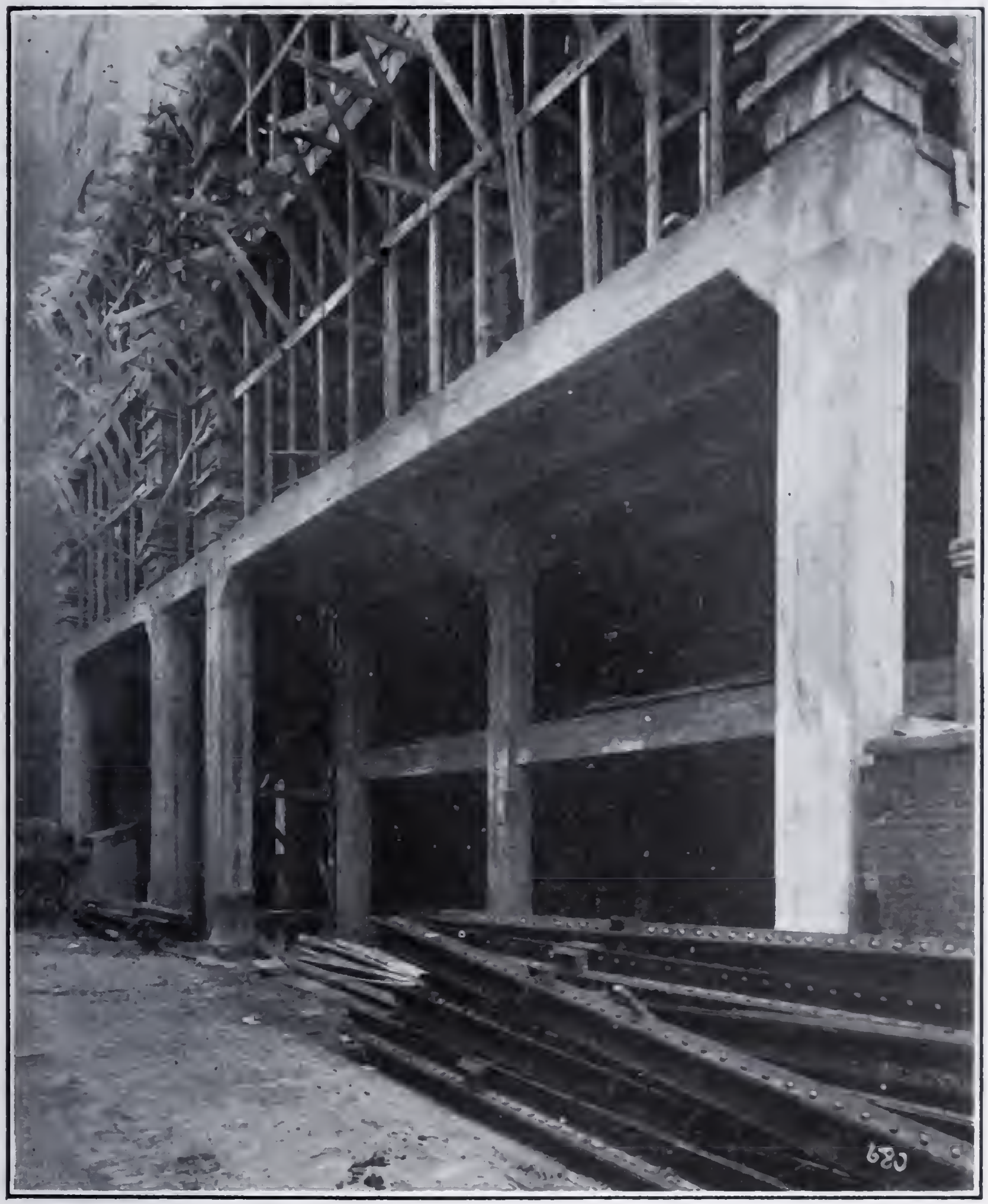


PLATE 8.—SPANDREL BEAM SUPPORTED BY REINFORCED CONCRETE CANTILEVER PROJECTING 7 FEET.

thickness of concrete surrounding the reinforcing members of reinforced concrete beams and girders shall be two inches on the bottom and one and one-half inches on the sides of the said beams and gir-

ders. The minimum thickness of concrete under slab rods shall be one inch. All reinforcement in columns to have a minimum protection of two inches of concrete.

All the requirements herein specified for the protection of steel and for fire-resisting purposes shall apply to reinforced concrete flooring between rolled-steel beams, as well as to reinforced concrete beams and to entire structures in reinforced concrete. Any concrete structure or the floor filling in same, reinforced or otherwise, which may be erected on a permanent centering of sheet metal, of metal lathing and curved bars or a metal centering of any other form, must be strong enough to carry its load without assistance from the centering, unless the concrete is so applied as to protect the centering as herein specified for metal reinforcement.

Exposed metal centering or exposed metal of any kind will not be considered a factor in the strength of any part of any concrete structure, and a plaster finish applied over the metal shall not be deemed sufficient protection unless applied of sufficient thickness and properly secured, as approved by the Chief of the Bureau of Building Inspection.

All concrete shall be mixed in a mechanical batch mixer to be approved by the Bureau of Building Inspection, except when limited quantities are required or when the condition of the work makes hand mixing preferable; hand mixing to be done only when approved by the Bureau of Building Inspection. In all mixing the material shall be measured for each batch.

When hand mixing is done under the aforesaid limitations, the cement and fine gravel or coarse sand shall be first thoroughly mixed dry and then made into a mortar by gradually adding the proper amount of water. The crushed stone or gravel shall be spread out to a depth not to exceed six inches, in a tight box or upon a proper floor, and be sprinkled with water as directed; the mortar is then to be evenly spread over the crushed stone, and the whole mass turned over a sufficient number of times, to effect the thorough mixing of the ingredients.

All forms and centering for concrete shall be built plumb and in a substantial manner, made tight so that no part of the concrete mixture will leak out through cracks or holes, or joints, and after completion shall be thoroughly cleaned, removing shavings, chips, pieces of wood and other material, and no debris of any kind shall be permitted to remain in the forms. All forms to be properly supported and braced

in a manner to safely sustain the dead load and the load that may be imposed upon them during construction.

The reinforcing steel shall be accurately located in the forms and secured against displacement.

Concrete shall be placed immediately after mixing.

Whenever fresh concrete joins concrete that is set, or partially set, the surface of the old concrete shall be roughened, cleaned and spread with cement mortar, which mortar shall be mixed in proportions of one of cement to two of sand.

Concrete shall not be mixed or deposited in freezing weather, unless precautions are taken to avoid the use of material covered with ice or snow or that are in any other way unfit for use, and that further precautions are taken to prevent the concrete from freezing after being put in place. All forms under concrete so placed to remain until all evidences of frost are absent from the concrete and the natural hardening of the concrete has proceeded to the point of safety.

Concrete laid during hot weather shall be drenched with water twice daily, Sunday included, during the first week. The broken stone, if hot and dry, must be wet before going to the mixer.

The time at which props or shores may safely be removed from under floors and roofs will vary with the condition of the weather, but in no case should they be removed in less than two weeks; provided, that column forms shall not be removed in less than four days: provided, further, that the centering from the bottom of slabs and sides of beams and girders may be removed after the concrete has set one week, provided, that the floor has obtained sufficient hardness to sustain the dead weight of the said floor and that no load or weight shall be placed on any portion of the construction where the said centers have been removed.

The concrete for all girders, beams, slabs and columns, shall be mixed in the proportions of one of cement, two of sand or fine gravel, and four of other aggregates as before provided. The concrete used in reinforced concrete-steel construction must be what is usually known as a "wet" mixture. When the concrete is placed in water it must be placed in a semi-dry state.

Only Portland cement shall be permitted in reinforced concrete constructed buildings. All cement shall be tested, in carload lots when so delivered or in quantities equal to same, and report filed with the Bureau of Building Inspection before using it in the work. Cement failing to meet the requirements of the accelerated test will be rejected.

Soundness, Accelerated Test.—Pats of neat cement will be allowed to harden twenty-four hours in moist air, and then be submitted to the accelerated test as follows: A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for three hours, after which, before the pat cools, it is placed in the boiling water for five additional hours.

To pass the accelerated test satisfactorily, the pat shall remain firm and hard, and show no signs of cracking, distortion or disintegration.

Such cements, when tested shall have a minimum tensile strength as follows: Neat cement shall, after one day in moist air, develop a tensile strength of at least 150 pounds per square inch; and after one day in air and six days in water shall develop a tensile strength of at least 500 pounds per square inch; and after one day in air and twenty-seven days in water shall develop a tensile strength of at least 600 pounds per square inch. Cement and sand tests composed of one part of cement and three parts of crushed quartz shall, after one day in air and six days in water, develop a tensile strength of at least 175 pounds per square inch, and after one day in air and twenty-seven days in water shall develop a tensile strength of at least 240 pounds per square inch. These and other tests as to fineness, set, etc., made in accordance with the standard method prescribed by the American Society of Civil Engineers, may, from time to time, be required by the Bureau of Building Inspection.

Walls.—Reinforced concrete may be used in place of brick and stone walls, in which cases the thickness may be two-thirds of that required for brick walls as shown in the Schedule, Section 18 of the Act of Assembly No. 123, of the Commonwealth of Pennsylvania, approved June 5, 1901, provided the unit stresses as set forth in these regulations are not exceeded.

Concrete walls in such cases must be reinforced in both directions in a manner to meet the approval of the Chief of the Bureau of Building Inspection.

Steel.—All reinforcements used in reinforced concrete shall be of standard grade of structural steel or iron of either grade to meet the "Manufacturers' Standard Specifications," revised February 3, 1903.

Reinforced concrete slabs, beams and girders shall be designed in accordance with the following assumptions and requirements:

(a) The common theory of flexure to be applied to all beams and members resisting bending.

(b) The adhesion between the concrete and the steel is sufficient to make the two materials act together.

(c) The design shall be based on the assumption of a load four times as great as the total load (ordinary dead load plus ordinary live load).

(d) The steel to take all the tensile stresses.

(e) The stress-strain curve of concrete in compression is a straight line.

The ratio of the moduli of elasticity of concrete to steel:

Stone or gravel concrete	1 to 12
Slag concrete	1 to 15
Cinder concrete	1 to 30

The allowable unit transverse stress upon concrete in compression:

Stone or gravel concrete	600 lbs. per sq. in.
Slag concrete	400 " " " "
Cinder concrete	250 " " " "

The allowable unit transverse stress in tension:

Iron	12,000 lbs. per sq. in.
Steel	16,000 " " " "

The allowable unit shearing strength upon concrete:

Stone or gravel concrete	75 lbs. per sq. in.
Slag concrete	50 " " " "
Cinder concrete	25 " " " "

The allowable unit adhesive strength of concrete:

Stone or gravel concrete	50 lbs. per sq. in.
Slag concrete	40 " " " "
Cinder concrete	15 " " " "

The allowable unit stresses upon concrete in direct compression in columns:

Stone or gravel concrete	500 lbs. per sq. in.
Slag concrete	300 " " " "
Cinder concrete	150 " " " "

The allowable unit stress upon hoop columns composed of stone or gravel concrete shall not be over 1,000 pounds per square inch, figuring the net area of the circle within the hooping. The percentage of longitudinal rods and the spacing of the hoops to be such as to permit the concrete to safely develop the above unit stress with a factor of safety of four.

When steel or iron is in the compression sides of beams the proportion of stress taken by the steel or iron shall be in the ratio of the modulus of elasticity of the steel or iron to the modulus of elasticity of the concrete; provided, that the rods are well tied with stirrups connecting with the lower rods of the beams; provided, further, that when rods are used in compression, the approval of the Chief of the Bureau of Building Inspection must be obtained.

In the design of structures involving reinforced concrete beams and girders, as well as slabs, the beams and girders shall be treated as T-beams, with a portion of the slab acting as flange in each case. The portion of the slab that may be used to take compression shall be dependent upon the horizontal shearing stress that may exist in the beam, and in no case shall the slab portion exceed twenty (20) times the thickness of the slab.

All reinforced concrete T-beams must be reinforced against the shearing stress along the plane of junction of the rib and the flange, using stirrups throughout the length of the beam. Where reinforced concrete girders carry reinforced concrete beams, the portion of the floor slab acting as flange to the girder must be reinforced with bars near the top, at right angles to the girder, to enable it to transmit local loads directly to the girder and not through the beams, thus avoiding an integration of compressive stresses due to simultaneous action as floor slab and girder flange.

In the execution of work in the field, work must be so carried on that the ribs of all girders and beams shall be monolithic with the floor slabs.

In all reinforced concrete structures special care must be taken with the design of joints to provide against local stresses and secondary stresses due to the continuity of the structures.

Shrinkage and thermal stresses shall be provided for by the introduction of steel.

In the determination of bending moments due to the external forces, beams and girders shall be considered as simply supported at the ends, no allowance being made for continuous construction over supports. Floor slabs, when constructed continuously, and when provided with reinforcement at top of slab over the supports, may be treated as continuous beams, the bending moment for uniformly distributed loads being taken at not less than $\frac{WL}{10}$ in case of square floor slabs which are reinforced in both directions and supported on all sides,

the bending moment may be taken at $\frac{WL}{20}$; provided, that in floor slabs in juxtaposition to the walls of the building the bending moment shall be considered as $\frac{WL}{8}$, when reinforced in one direction, and if the floor slab is square and reinforced in both directions, the bending moment shall be taken as $\frac{WL}{16}$.

When the shearing stresses developed in any part of a reinforced concrete building exceed under the multiplied loads the shearing strength as fixed in this section, a sufficient amount of steel shall be introduced in such a position that the deficiency in the resistance to shear is overcome.

When the safe limit of adhesion between the concrete and steel is exceeded, provision must be made for transmitting the strength of the steel to the concrete.

Reinforced concrete may be used for columns in which the ratio of the length to least side or diameter does not exceed fifteen (15). If more than 15 diameters the allowable stress shall be decreased proportionally. Reinforcing rods that are introduced for lateral stresses must be tied together at intervals of not more than the least side or diameter of the columns.

Longitudinal reinforcing rods will not be considered as taking any direct compression.

The contractor must be prepared to make load tests in any portion of a reinforced concrete building within a reasonable time after erection, and as often as may be required by the Chief of the Bureau of Building Inspection. The tests must show that the construction will sustain a load equal to twice the calculated live load without signs of cracks.

Systems of construction differing from the standard already approved and tested, may be required to pass a load, fire and water test, as present in Section 2 of the Act of Assembly, No. 236, of the Commonwealth of Pennsylvania, approved April 25, 1903.

The Chief of the Bureau of Building Inspection may, from time to time, issue such modifications to these regulations as may be found necessary to conform to modern practice.

Approved, 10–8–07.

Henry Clay,
Director of the Dept. of Public Safety.

DISCUSSION.

Mr. Edwin Clark (Chief of Bureau of Building Inspection).—I must take exception to the statement of Mr. Ballinger relative to allowance being granted by the Bureau of Building Inspection for the continuity of girders over columns, for the following reasons: First, there may be a settlement in the column; second, usually there is not sufficient concrete furnished to take up the compressive forces in the lower section of the girders; third, girders usually have a certain number of straight bars and a certain number of bent bars. The moment at the centers of the girders for a uniform load is usually figured at $\frac{WL}{10}$; this includes not only straight bars but also the bent bars. The percentage of the bent bars is usually less than 50 per cent. of the total number of bars. Under these conditions, without additional bars being provided over the columns there would not be ample material there to take up the stresses for continuity. As far as inspection is concerned, we have been successful in having created the position of Engineer of Reinforced Concrete Construction, and we hope as time goes on to be able to increase the number as the exigencies of the case may require. Relative to the formulas which Mr. Perrot presents this evening, he is responsible for them himself, and the Bureau does not recognize them as their standards. His work, submitted upon his basis of figuring, is usually correct.

Relative to allowing an increase in stress due to longitudinal reinforcement, the Bureau will not allow for such longitudinal reinforcement for the following named reasons: First, the proportional part of the stress taken by the rods must be transmitted through the medium of the concrete; second, owing to the commercial length of the rods it is necessary to join them, and up to the present time there is no satisfactory detail for transmitting the loads from one rod to another; with the use of small longitudinal rods they are out of alignment and in every way present bad details. The longitudinal rods that the Bureau requires to be placed in the columns are put there to take up the lateral forces due to wind or any eccentricity that may be placed upon the columns.

R. W. Lesley (by letter).—The regulations of the Bureau of Building Inspection which are before us embody much that is good in reference to the important class of work desired to be covered, and especially valuable are those requirements relating to inspection and the actual details of the production of concrete itself.

While the growth of concrete construction in all our large cities has produced many specifications similar to that of the city of Philadelphia, it is to be regretted that the elaborate work at the Government testing laboratory at St. Louis, under the auspices of the Joint Committee on Concrete and Reinforced Concrete, has not been completed in time to enable all municipalities to have a standard specification. This work, the details of which are gradually being made public, is of so valuable a character that when it is produced as a whole, and specifications, based upon the conclusions drawn from the numerous experiments both of the materials of concrete and of the concrete itself in the form of beams, blocks, etc., are made, public specifications of uniform character are certain to follow which will be generally adopted by municipalities all over the country.

In this connection of the standardization of specifications and the likelihood

of their general adoption in the United States, it is to be regretted that in the Philadelphia specifications a material departure is made from the standard specifications for cement adopted by the American Society for Testing Materials as the result of deliberations of the joint committee of the various engineering societies which had the matter in hand. This specification, which has been circulated to the extent of about forty thousand copies to all parts of the United States and abroad, was, as is well known, the work of several years, and had as its basis the methods of manipulation of tests prescribed by the American Society of Civil Engineers. While the Philadelphia specification conforms in practically all its details to the specification above referred to, it fails to so conform in the important matter of accelerated tests, or tests for constancy of volume. In the specification of the American Society for Testing Materials, this test is prescribed as follows:

CONSTANCY OF VOLUME.

23. Pats of neat cement about three inches in diameter, one-half inch thick at the centre, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least twenty-eight days.

(*b*) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least twenty-eight days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

24. These pats, to satisfactorily pass the requirements shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

In the specification of the City of Philadelphia for reinforced concrete construction, it is prescribed, as follows:

> *Soundness, Accelerated Test.*—Pats of neat cement will be allowed to harden twenty-four hours in moist air, and then be submitted to the accelerated test as follows: A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely-closed vessel, for three hours, after which, before the pat cools, it is placed in the boiling water for five additional hours.
>
> To pass the accelerated test satisfactorily, the pats shall remain firm and hard, and show no signs of cracking, distortion or disintegration.

Thus it will be noted that the difference, practically, is that the pat which has been exposed to steam under the standard specification above referred to for five hours is, in the Philadelphia specification, exposed for three hours and then put in boiling water for an additional period of five hours. While this change in itself is not so material a one, it is a matter to be regretted that in the city of Philadelphia, which furnished a large number of members of the joint committee which made the standard specification, this first deviation from the requirements of the latter specification should be found to exist.

A reference to the literature on the subject of the accelerated test will reveal

that for years there were as many accelerated tests as there were engineering minds, and that each engineer in the making of a specification seemed to deem it his privilege and his opportunity to discover some new method of torturing Portland cement. This was especially the case in this country, as is referred to by the writer in a paper read before the American Society for Testing Materials in 1902,—before the standardization of specifications in this country began,—wherein were described ten different varieties of accelerated tests alone, and by an analysis of some two to three hundred American specifications it was found that in thirty-five of them when accelerated tests were named there were all varieties of the periods of time in which the pats were to go into the water; the kind of water and the temperatures of the same in which they were to go, and the time of exposure, whether in water or steam; or, in other words, there was no uniformity in this important method of testing, and all the elements were at the whim of the party prescribing it.

During all this period of hysteria on this test in this country the standard specification in Germany remained untouched, and remains untouched today, requiring merely exposure of the pats to air and cold water, and the same specification has but recently been re-enacted by the engineers and architects of Austria.

It is with regret, therefore, that the writer sees a tendency to unsettle by individual judgment that which has been once settled by the consensus of engineering brains selected as representatives by the following societies: The American Society of Civil Engineers, the American Society for Testing Materials, the Association of American Portland Cement Manufacturers, the American Railway Engineering and Maintenance of Way Association, and the Institute of Architects.

It is the thin edge of the wedge that counts, and if it is to be driven into the standard specification in this direction there is no reason why it should not be driven into it in all directions, and all likelihood of standardization and uniformity will be put an end to.

There is no doubt that the test prescribed can be met by all good American Portland cements, and is met in most manufactories having established testing laboratories, but it is not wise, in the writer's opinion, for an individual engineer or architect to proceed in this way to change established specifications, when the committee itself has the whole matter of a standard specification in hand, and is at the present moment receiving suggestions for modifications or changes that experience seems to indicate as advisable. These suggestions are to be reported upon at the next meeting of the American Society for Testing Materials, at Atlantic City in 1908. The writer cannot urge too strongly the adoption of the standard specification so far as tests for constancy of volume are concerned, as prescribed in the standard specification, as a substitute for that in the Philadelphia specification now under discussion.

Mr. Perrot.—Answering Mr. Lesley's remarks as to the wisdom of establishing a different standard for the soundness test of cement from that adopted by the American Society for Testing Materials would say that I am thoroughly in accord with Mr. Lesley's statement deprecating the adoption of various standards for testing cement or, in fact, with the introduction of different standards throughout the country for building materials of any sort. But in regard to the above test of cement, while the standard does differ from that promulgated by the

American Society for Testing Materials, the test approved by the Testing Society was not unanimously adopted nor was the test based on a prolonged series of tests made on cements to determine its preference to other methods of testing. It is conceded by high authority skilled in the testing of cement that actual comparative tests made on cements covering a period of at least six months, showed that the steam test was not as decisive in its results as a boiling test; in fact, the results indicated that a steam test, pure and simple, could and did so improve the cement that it showed no signs of failure, while boiling tests for a shorter period of time on samples of the same cement produced failure.

The testing laboratory of the city of Philadelphia has not adopted the steam test approved by the American Society for Testing Materials, deeming it not of sufficient rigor to always detect an unsound cement. The standard required by the new regulations of reinforced concrete combines both the steam and boiling tests, and in this feature may be said to be a compromise.

Mr. James S. Merritt.—I think the committee is to be congratulated on these specifications, and that they cover the case admirably. But there is one point that I would refer to: "The minimum thickness of concrete under slab rods shall be one inch." At various times within the last ten years I have seen numerous tests of full sized beams and floor sections, some of which have been very severe. I think that in every case the reinforcement, whether of the mesh type or the rod type, has been exposed, and I do not recollect any case where the slab has failed under fire or under load, so that the requirement of one inch seems a little severe.

I would like to ask whether Mr. Perrot knows any practical way of keeping the reinforcement 1 inch away from the centers. If left to the workman, he may get the reinforcement up ¼ inch or he may get it up 2 inches. On the other hand, if there is any form of spacer put under the rods, the placing of the concrete is almost sure to knock the spacers out. I do not know anything that has given us more trouble than this question of keeping the rods away from the centers.

Mr. Perrot.—In reference to putting the rod one inch from the bottom of the concrete, I may say that that is one of the hardest things to do in reinforced concrete construction. Some constructors use cement blocks 1 inch thick to keep the rods off the forms, and some use a small chair of wire projecting down from the rods while others use an iron spacer.

H. G. Perring (by letter).—The preparation of regulations for the use of reinforced concrete is a labor of love, and the thanks of the citizens of the city are due to the committee of the Engineers' Club who so carefully and so faithfully performed this labor, and brought forth the regulations which now have the stamp of approval of the Director of Public Safety and of the Chief of the Bureau of Building Inspection.

Probably the primary and principal consideration of the committee in its deliberations was to produce regulations applicable to the general run of contractors, men of no particular scientific training. Regulations so designed are probably for the general welfare, and certainly insure safety when reasonable care is exercised in the design and execution of the work. As the rain descends alike on the just and the unjust, so, it seems, these regulations affect both the competent and the incompetent. A premium is placed on mediocrity, and scientific ability to cope with problems in reinforced concrete design is discouraged.

The highest scientific production in reinforcement, as exemplified in the General Fireproofing Company's girder frame, is placed on the same level as the most slipshod placing of plain steel rods, with the most meagre provision for horizontal shear and diagonal tension.

The statement that beams and girders shall be considered as simply supported at the ends is not in accordance with scientific theory or fact.

It is a fact that any beam, monolithic or firmly cemented, over three or four supports will act with all the phenomena of continuous beams. In such a system of beams a negative bending moment will be developed over the supports, and a positive moment approximately one-half as great will be developed in the center of the span. If the beam is calculated as being simply supported, the action will nevertheless be that of a continuous beam.

It has been claimed that true continuity cannot be secured, particular reference being made to beams of T section. By carrying the tension members at the top of the beam across the point of support, and providing steel in the compression side of the beam at this point, there is no reason why we should not get a construction of at least equal efficiency to that secured by using a width of flange in the T beam of twenty times the thickness of the slab, which is now allowed by the regulations. The action of the slab flange of a T beam is surrounded by more difficulties of analysis than is the continuous action of beams. The condition of the supports determines the action of a continuous beam. The support of a beam crossing a girder is not absolutely rigid, which must modify our formula, but where girders run across columns, there can be but little doubt that fixed supports are found, and the action becomes truly that of a beam fixed at both ends. As a compromise upon these two conditions, the same formula for continuity of beams is suggested that the regulations allow for slabs, viz., $\frac{WL}{10}$. This compromise should not be firmly fixed if a competent designer is desirous of using the true continuity of the beams, and makes due allowance for maximum moment due to unequal loading.

The competency of a designer may amount to naught if the work is executed carelessly. Eternal vigilance is necessary, and the regulations wisely state that the execution of the work shall be directed by a competent superintendent. Unfortunately it is not in the province of these regulations to state who and what shall determine the competency of the superintendent. It is very doubtful if a police regulation can touch upon such a point. This one paragraph in the regulations suggests at once the thought of a test of fitness for all those who design or direct engineering work, which, in its broad sense, includes the practice of architecture. Such a test should be required by law, a license given, and a definite responsibility placed upon the licensee. An act of legislature would be required to secure such a law, and it seems within the province of this Club to demand legislation toward such an end.

In view of the regulations which have been adopted, that portion of the Building Laws referred to as "Section 2 of Act of Assembly No. 236 of the Commonwealth of Pennsylvania, approved April 25th, 1903," requiring systems of construction to pass combined load, fire, and water tests, should be repealed, and a provision inserted requiring that constructions capable of scientific analysis shall be accepted, when such construction is designed in accordance with the regulations of the Bureau of Building Inspection.

A fire test of reinforced concrete construction is expensive, costing about two thousand dollars, and as all such systems must come within the regulations, a test of one system is a test of all. Other so-called systems, not capable of accurate scientific analysis, at the present state of the art, should stand the test as at present called for.

Mr. Trautwine.—In the "Regulations of the Bureau of Building Inspection in Regard to the Use of Reinforced Concrete" I read:

> "The time at which props or shores may safely be removed from under floors and roofs will vary with the condition of the weather, but in no case should they be removed in less than two weeks; provided, that column forms shall not be removed in less than four days; provided, further, that the centering from the bottom of slabs and sides of beams and girders may be removed after the concrete has set one week, provided, that the floor has obtained sufficient hardness to sustain the dead weight of the said floor and that no load or weight shall be placed on any portion of the construction where the said centers have been removed."

Regarding this paragraph, two questions strike me as pertinent: first, What is the limit of time intended to be set by the Bureau for the removal of props or shores? and second, Why go to the trouble of constructing concrete floors if, as here provided, "no load or weight shall be placed on any portion of the structure where the said centers have been removed"?

I would suggest that, in future editions of the "Regulations," the paragraph in question be accompanied by Mr. Perrot's explanation. Further, I am inclined to think, after having heard Mr. Perrot's explanations, that the paragraph may mean something like the following:

1. Props under floors and roofs must remain in place at least two weeks.
2. Column forms must remain in place at least four days.
3. The centering under the bottom of slabs and at the sides of beams and girders must remain in place at least one week, and at least so much longer as is necessary for the floor to obtain sufficient hardness to sustain its own dead weight.
4. No load or weight shall be placed on any portion of any floor from under which the props have been removed, until two weeks from the time of construction.

The paragraph in question begins with the clause: "The time at which props or shores may safely be removed from under floors and roofs will vary with the condition of the weather." In my rendering of the paragraph, I have omitted this clause; first, because the paragraph immediately proceeds to fix the time independently of the weather; and, second, because of the apparently limited usefulness of the clause.

The initiated are probably already aware that the time in question varies with the weather; and, to the uninitiated, the clause is of little value, because it does not indicate the *extent* to which weather conditions affect the time for keeping the props in place, or whether that time is to be *lengthened* or *shortened* for dry weather, for hot weather, etc.

Taking it for granted that Mr. Perrot's explanation has enabled us to guess correctly as to the answers to the two questions previously submitted, two others seem to have arisen in their places, namely:

1. How is the builder to know, *before removing the centering*, whether "the

floor has obtained sufficient hardness to sustain the dead weight of the said floor"? and,

2. Seeing that it is so easy to express what appears to be meant by the paragraph, why insist upon leaving it unintelligible, even to the uninitiated?

In the early portion of his remarks, Mr. Perrot defended the provision, in the Bureau Regulations, that "the concrete for all girders, beams, slabs and columns shall be mixed in the proportions of one of cement, two of sand or fine gravel, and four of other aggregates as before provided."

Comparing this requirement with the practice of using a 1–2–4 concrete for columns, and a poorer concrete for beams and floors, Mr. Perrot placed upon the board a sketch, and pointed out that the small and nearly cubical volume of concrete, properly part of the floor beams, and coming between the top of the lower column and the foot of the upper one, ought to be of equally good material with the columns themselves, because, as he remarked, "A chain is no stronger than its weakest link."

Admitting this well-known fact, and without presuming to criticize the provision in question, I submit that the quotation used is hardly applicable to this case; because this small and approximately cubical bit of concrete, between the two columns, is absolutely confined on each of its six sides, and is therefore in the best possible position for withstanding pressures upon it; whereas the columns, although short, are nevertheless columns, and therefore should not be entrusted with even so great a unit load as would be proper upon an unconfined short block.

I venture to say that if the two columns, with the confined block of concrete between them, were tested to destruction by a load on top of the upper column, the failure would take place in the columns and not in the confined block, even though said block were made of 1–3–6 concrete, while the columns were of 1–2–4. *In other words, even under these circumstances, the columns, notwithstanding their better material, would, I believe, be found the weakest link in the chain.*

Mr. Perrot.—Answering Mr. Trautwine's criticism of the wording of that part of the regulations relating to the removal of "shores" and "forms," it is necessary, before answering his remarks in detail, to make clear in the minds of the uninitiated the meaning of the words props, shores, forms, and centering, as applied in the regulations, after which it will be clear that the wording is entirely explicit. Props or shores mean the vertical supports under the forms, that is, the vertical elements in a system of centering which run from a solid foundation to the bottom of the forms or boxes, which boxes are the elements that receive the plastic concrete, the props possessing the same function as a post or column in any floor system.

Forms or centering mean the moulds or box-like construction of a floor into which the concrete is poured to obtain its final shape, and is independent of the props or shores, as in some cases props or shores are omitted and trusses used to support the forms spanning from column to column with jack trusses resting on the principal trusses.

Having these definitions in mind, it is clear that forms can be so designed (and they are) that the props can remain in position an indefinite length of time, and yet the forms can be taken down immediately after the concrete is poured

if it is so desired; hence it is necessary to state the time the props must remain in position and also the time the forms must remain in position.

This the regulations clearly do with the added provision that the condition of the weather must be taken into account. All users of cement and concrete know that the colder and damper the weather, the longer the cement or concrete will take in setting; to attempt to define in the regulations at just what period the concrete is able to stand up in cold weather without the aid of forms, is somewhat parallel to telling the cook just when the cake is baked, for the third paragraph of the regulations requires that "the work shall be performed by workmen under the *direct* supervision of a *competent** foreman or superintendent," and any competent foreman can tell when the concrete is in condition to have the forms removed.

Answering Mr. Trautwine's further remarks, concerning the layer of concrete in the column coinciding with the thickness of floor beams and girders, the illustration he makes use of, in which beams butt into and rest on four sides of a column, is by no means a universal condition. I have in mind one building in which almost 50 per cent. of the columns have light spandrel or wall-beams resting on two sides of the columns only, and then in some cases the beams are only 12 inches wide while the column is 26 inches square, with the beam flush with the outside face; these columns are wall columns and are not analogous to interior columns with beams abutting the four sides. Further, some interior columns have beams abutting three sides. In four buildings I have designed, this condition occurs, hence there is no certainty that the column will be reinforced at the floor level with beams abutting the four sides, and consequently the provision of the regulations regarding the proportions of the concrete is most excellent.

Mr. Ballinger.—We are using on one of our buildings a method of keeping the slab rods one inch away from the center by having little blocks about 4 inches long and 2½ inches wide with beveled ends set the small side down, so that the rods are set on these molded blocks. They are easily molded in gangs, and molded equally. When they are a few days old they are good enough to put on the forms. That is being done successfully.

There is a great deal of discussion about the weakness of concrete, and I think it only fit to emphasize its strong points. In the formulas for calculating the stresses, I think there is no allowance made for continuity, with the exception of slabs. As a rule, we do get continuity, in nine cases out of ten. I think that the formula $\frac{Wl}{10}$, which is half or midway between the value of continuous beam formula and simple beam formula, would be pretty nearly correct; that is, as to the actual results obtained under ordinary conditions, and the fact that it is so well tied together makes the building with the other parts help to carry it. At the Franklin Institute Mr. Merritt gave a paper two or three years ago, I recollect, where steel beams had been used concreted, and concrete slabs made of expanded metal had been placed in connection with it; the beam had been entirely cut away, through some ignorance, and the slab was carrying the beam which was supposed to carry it.

There is one other note: I do not know whether or not the Building Department

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* Italics supplied by author.

is provided sufficiently with the means of enforcing these regulations. So far as an examination of the plans and checking them up is concerned, it is all that we could desire. They make thorough check, and I think they are safe and efficient in what they do.

In regard to the new inspector, I do not care how efficient he may be, he cannot cover half the ground. One, or five, or ten men could not do it. In our practice we feel that if we want to watch a building thoroughly, to see that everything goes in exactly as called for, we should have a man on the building, and in most cases we do that. Therefore I do not think we should expect too much of the Building Department in this particular. Owners are sometimes inclined to think that the Building Department must see that nothing goes wrong, and that is a physical impossibility. One man cannot be on several buildings at once.

OBITUARY OF CHARLES HAYNES HASWELL.

CIVIL, MARINE, AND MECHANICAL ENGINEER.

Mr. Charles H. Haswell died at his home in New York City, Sunday afternoon, May 12th, from a shock attending the dislocation of a shoulder occasioned by a fall. He was born in North Moore St., New York City, on May 22, 1809, and had, therefore, reached within a few days the age of ninety-eight years. He was frequently spoken of as the oldest living engineer.

Mr. Haswell had enjoyed good health during his whole life and practised his profession until the time of his death. He was of English parentage, his father was a native of Dublin, and his family were among the Royalists who in the last century migrated to the Barbadoes, W. I.

He graduated at the Collegiate Institution of Rosa Nelson in New York, and at the age of nineteen commenced a large and useful professional life as assistant at the engine works of James P. Allaire, New York City, in 1828, which was then the largest steam-engine building shop in the United States. The work at this shop gave him excellent practical knowledge and experience which later was of great benefit to him in his ship-building work.

In 1836 he received an appointment as U. S. Naval Engineer, and in 1834 was promoted to the position of Engineer-in-Chief, the first to be appointed to this rank. In 1836 he designed engines and boilers for the U. S. steam frigate "Fulton," designed the machinery for ten warships, constructed in 1837 at the Brooklyn Navy Yard the steam launch named "Sweetheart," the first steam yacht ever launched, which made him known as the father of the steam yacht.

Mr. Haswell, in 1847, was the first to introduce the use of zinc in marine boilers and in the bottom of iron vessels, to arrest oxidation from the action of sea water.

In 1847 and 1848 Mr. Haswell designed the entire engine and boiler equipment of the U. S. steam frigate "Powhatan," one of Commodore Perry's fleet in the memorable expedition to Japan, including every detail and making the working drawings with his own hands in the intervals he could find among his necessary duties as Chief Engineer of the Navy. In some parts the design of the engine was novel, in the

fact that the engines were set in wrought-iron frames, the first construction of its kind.

He resigned from the navy in 1851, and went into private practice, designing and building various steamships and merchant vessels, for which his qualifications were well adapted.

In 1853 he was decorated by Emperor Nicholas for some professional service he had rendered the Russian Government.

It is stated that Mr. Haswell resigned from the navy because he would not agree to the proposition that two pipes of 3½ feet in diameter were equal in capacity to one of 7 feet in diameter, which disagreement was held to be disrespectful to his superior officers. It has also been stated that his resignation was due to the fact that it was proposed to build the "Missouri" with horizontal smokestakes and to his zealous opposition to this scheme. When later Mr. Haswell's contention, whichever it may have been, was found to be correct and he was asked to apologize for his insubordination, he is said to have replied "I prefer to submit to injustice from others than to be unjust to myself. I decline to make the apology, as I owe none."

From 1851 to 1893 Mr. Haswell held the position of surveyer of steamers for the marine underwriters of New York, Boston, and Philadelphia, and he had been at certain times engineer of the Health Department, of the Department of Charities and Correction, and Trustee of the New York and Brooklyn Bridge. He designed and constructed a ballast bulkhead crib at Harts Island and the set of buildings on Hoffman Island, New York Bay. In 1858 he was President of the Civil Board of Councilmen of the City of New York. From April, 1861, to the summer of 1863, he rendered important services under General Burnside in the War of the Rebellion. From 1898 to 1901 he was consulting engineer to the Board of Public Improvements, and from 1902 until the time of his death he was entered on the city payroll as Assistant Engineer to the Board of Estimate and Apportionment.

At the time of his death he was superintending the construction of city works at Rikers Island.

Mr. Haswell was the author of a number of books, papers, and articles, the most important of which was his "Engineers' and Mechanics' Pocket Book," first issued in 1843, and of which the seventy-second edition was published in 1906. This book is truly a *multum in parvo*, and shows much original work and research. In 1854 he published "Mechanics' Tables," and in 1860 "Bookkeeping" and "Mensuration."

He also wrote a most interesting volume in 1897 entitled "Reminiscences of an Octogenarian of New York, 1816–1860."

In 1897 Mr. Haswell attended the convention of the Institution of Naval Architects of Great Britain, and at the annual meeting in 1898 he presented a paper entitled "Reminiscences of Early Marine Steam Engines and Construction and Navigation in U. S."

Mr. Haswell was a member of the Franklin Institute, Institution of Civil Engineers, Engineers' Club of New York, New York Academy of Science, American Institute of Architects, and Naval Architects, Society of Municipal Engineers of New York, and was honorary member of the Engineers' Club of Philadelphia, American Society of Naval Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers, and Boston Society of Civil Engineers. He was also a member of Tammany Hall in New York.

Mr. Haswell was married in 1829 to Miss Ann E. Burns, of New York City, and has had three sons and three daughters. He was fond of telling stories of his early life at the Engineers' Club, among which the following was a favorite:

When there was a shortage of orders at the Allaire Works Mr. Haswell suggested that a tugboat should be built for New York City, because it would probably soon be needed. Mr. Allaire thereupon is said to have replied: "Why build a tugboat when there are three in the harbor already?"

Mr. Haswell was erect and tall in figure and his movements little showed the weight of his age. He learned to ride on a bicycle when eighty-eight years old and enjoyed the exercise. His character was marked by courage, independence and fearlessness and his personality was decidedly attractive. In his dealings with others he was always courteous and without official reserve. He was a familiar figure at the Engineers' Club of New York and was beloved by a wide circle of friends.

After Mr. Haswell's death Mayor McClellan of New York notified the aldermen of his demise, and in an appropriate message referred to the more important and interesting incidents in his long and distinguished career.

RUDOLPH HERING,
HENRY G. MORRIS,
WASHINGTON JONES.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, September 21, 1907.—President Quimby in the chair. One hundred and thirty-seven members and visitors present.

The Secretary read a memorial of Honorary Member Charles Haynes Haswell.

President Quimby presented the proposed amendments to the By-Laws, to be voted on on November 2d.

The Nominating Committee, as previously announced, was duly approved.

Prof. S. G. Comfort presented a paper on "The Quebec Bridge."

Business Meeting, October 5, 1907.—President Quimby in the chair. Eighty-five members and visitors present.

The tellers announced the election of E. E. Bratton to active membership, and C. Clifford Wilson to junior membership.

President Quimby gave an informal talk on the Walnut Lane Bridge to which the Club had made an excursion in the afternoon.

Business Meeting, October 19, 1907.—President Quimby in the chair. Ninety-six members present.

Mr. Perrot gave an illustrated talk on the proposed new Club-house.

Mr. Christie offered a resolution directing the Board to complete the purchase of the new Club-house, and to issue bonds to be secured by second mortgage, to complete the purchase and provide money for furnishing and altering the house. The motion was carried unanimously.

Business Meeting, November 2, 1907.—President Quimby in the chair. Eighty-three members and visitors present.

The tellers announced the election of Fred W. Abbott, Geo. H. Benzon, Jr., Norman Z. Ball, M. Ward Easby, W. L. Haynes, H. F. Huy, Lewis H. Kenney, T. Kolischer, G. M. Norman, J. Livingston Poultney, C. W. Palmer, Percival M. Sax, H. R. White, Rollin A. Whittick, and Jas. C. Wobensmith to active membership; Louis S. Bruner, Edw. J. Dauner, Edward Hoopes, and Michael Monaghan to junior membership; and Carl A. Albrecht, W. Irwin Cheyney, and Elmer E. Melick to associate membership.

The secretary announced the result of the balloting on the proposed amendments to the By-Laws:

Amendment.	*Total Votes Cast.*	*Votes for.*	*Votes against.*	*Necessary for Adoption ⅔.*
Art. I, Sec. 4	216	42	174	144
Art. I, Sec. 7	215	42	173	144
Art. IV, Sec. I	202	175	27	135
Art. IV, Sec. 3	203	177	26	136
Art. IV, Sec. 6	199	177	22	133
Art. IV, Sec. 7	200	186	14	134
Art. V, Sec. 10	200	178	22	134
Art. VI, Sec. 1	204	157	47	136
Art. VII Sec. 1	203	164	39	136

Attention was called to the fact that the ballot made no provision for voting separately on the two sections of Art. VI and Art. VII, and it was moved and carried that the votes recorded as the proposed amendment to Art. VI and Art. VII be understood to apply to both sections as submitted; and that the second paragraph of old Sec. 2, Art. VI, be added to the new Sec. 2, Art. VI.

The Club expressed its appreciation of the efforts made by the Board of Directors and the Secretary and Treasurer during the past six months in carrying to successful fruition the purchase of the new Club-house.

The following resolution was presented and duly carried:

"*Resolved:* That it is the sense of this meeting that the true future policy of the Club should be to enlarge and develop the technical work of the Club, and that other activities, arising from the increased facilities, should always be subordinate to this."

Mr. Emile G. Perrot presented a paper on "The New Regulations of the Bureau of Building Inspection of the City of Philadelphia in Regard to the Use of Reinforced Concrete."

Business Meeting, November 16, 1907.—President Quimby in the chair. Ninety members and visitors present.

The Nominating Committee presented the following nominations for officers:

For President,	H. W. Spangler
" Vice-President (two years),	Washington Devereux
" " (three years),	Wm. Easby, Jr.
" Secretary,	Francis Head
" Treasurer,	Geo. T. Gwilliam
" Director (one year),	F. E. Dodge
" " (two years),	J. O. Clarke
" " " "	H. G. Perring
" " " "	Henry H. Quimby
" " " "	Wm. S. Twining
" " (three years),	James Christie
" " " "	H. P. Cochrane
" " " "	Richard G. Develin
" " " "	Henry Hess

Mr. F. Jaspersen was appointed a delegate to the Atlantic Deeper Waterways Conference.

President Quimby announced the decision of the Board regarding the status of juniors already elected and to be elected before January 1, 1908, viz., that such juniors should not be required to pay an additional fee upon their advancement to active membership.

The Secretary announced the deaths of Mr. Pat. Doyle and Mr. Thos. A. Roberts, active members, who died March 27, 1907, and February 11, 1907, respectively.

Prof H. C. Parker read a paper on "The Helion Lamp."

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Special Meeting, July 11, 1907.—Present: President Quimby; Vice-Presidents Dallett and Devereux; Directors Dodge, Easby, and Perrot, and the Treasurer; Mr. Dallett acting as Secretary prò tem.

The object of the meeting was the discussion of the proposed lease of the house No. 1317 Spruce Street, and the following resolution was made and passed in pursuance of the resolution adopted at the meeting of the Club on July 1st: "*Resolved*: That The Engineers' Club of Philadelphia lease the premises No. 1317 Spruce Street, Philadelphia, from John G. Carruth and Adelaide K. Carruth, for a period of three years from September 1, 1907, at the rental of $4000 per annum, with an option or privilege to purchase the said premises at any time during the continuance of said lease for the sum of $70,000, clear of all incumbrance, and that the proper officers of the Club be, and they are hereby authorized to execute and deliver the form of lease and agreement embodying said terms."

Special Meeting, August 16, 1907.—Present: President Quimby; Vice-President Dallett; Directors Dodge, Easby, and Perrot, and the Secretary and the Treasurer.

The object of the meeting was to hear the report of the Committee appointed to execute the lease of the new Club-house, which showed that Mrs. Carruth had refused to execute the lease to No. 1317 Spruce Street.

It was moved and carried that the Committee should prepare a statement regarding the negotiations, to be sent to the members with the notice for the meeting of September 21st.

Special Meeting, September 10, 1907.—Present: President Quimby; Vice-Presidents Dallett and Devereux; Directors Dodge, Easby, Head, and Perrot; and the Secretary and the Treasurer. A special invitation was also extended to all of the Past-Presidents of the Club.

The object of the meeting was the consideration of the project for a new Club-house.

The following resolutions were moved and adopted:

Resolved: That a Committee be appointed to continue the search for a desirable property and report definitely on two or three of the best available properties.

Resolved: That a Committee be appointed to confer with the Managers of the Franklin Institute on the question of co-operating with the Franklin Institute in obtaining Club quarters.

Resolved: That a Committee be appointed to canvass the membership on the question of subscribing for bonds in the event that a suitable opportunity to purchase a Club-house is obtained.

Regular Meeting, September 18, 1907.—Present: President Quimby; Vice-Presidents Dallett and Devereux; Directors Dodge, Easby, and Perrot; and the Secretary and the Treasurer.

The report of the Treasurer for the months of June, July, and August was read and accepted as follows:

Balance, May 31, 1907,		$5354.44	
Receipts:			
June, ...	$510.00		
July, ...	75.00		
August, ...	410.85	995.85	$6350.29
Disbursements:			
June, ...	$745.08		
July, ...	531.21		
August, ...	825.05	2101.34	2101.34
Balance, August 31, 1907, ...			$4248.95

The Special Property Committee appointed on February 11, 1907, made a formal report that the property on the corner of Camac and St. James Streets had been sold to another party at a higher price, and the Committee was therefore discharged from further consideration of the question.

The following committees were appointed by the Board:

First: As members of the committee to continue the search for a desirable property and report definitely on two or three of the best available: Gwilliam, Dallett, H. E. Havens, Loomis, and Perrot.

Second: As a committee to confer with the Managers of the Franklin Institute on the question of co-operating with the Franklin Institute: Marburg, Christie, Geo. S. Webster, Quimby, and Easby.

Third: As a committee to canvass the membership on the question of subscribing for bonds in the event of a suitable property being obtained: Spangler, Dallett, Gwilliam, Lober, and Twining.

It was moved and carried that the Search Committee be authorized to secure an option on the Potts property, No. 1317 Spruce Street, at a price not to exceed $70,000, and to pay earnest money of not more than $2000, and that the President and Treasurer be authorized to pay such earnest money on the requisition of the Committee.

Special Meeting, October 11, 1907.—Present: President Quimby; Vice-President Devereux; Directors Dodge, Loomis, Perrot, and Head; and the Treasurer; Director Head acting as Secretary pro tem.

The object of the meeting was to hear the report of the Search Committee. This committee reported that they had engaged Frederick Sylvester to represent the Club in the negotiations toward the purchase of No. 1317 Spruce Street from John G. Carruth and Adelaide K. Carruth. They presented a statement from Frederick Sylvester to the effect that he had paid $1000 earnest money to John G. Carruth and Adelaide K. Carruth, and outlining the further terms of settlement.

It was moved and carried that the Treasurer be empowered to employ Francis G. Taylor to draw up resolutions to be passed by the Club and by the Board

of Directors in proper form for the perfection of the purchase of No. 1317 Spruce Street.

Adjourned Special Meeting, October 14, 1907.—Present: President Quimby; Vice-President Dallett; Directors Dodge, Easby, Head, and Perrot; and the Secretary and the Treasurer.

It was agreed that an estimate of the probable cost of altering and improving the house No. 1317 Spruce Street should be obtained, so that a report could be made to the Directors on October 15th.

Adjourned Special Meeting, October 15, 1907.—Present: President Quimby; Vice-President Dallett; Directors Dodge, Head, and Perrot; and the Secretary and the Treasurer:

The evening was devoted to a discussion of the letter sent by the Board of Directors to the membership, which gave a statement of the cost of purchasing, altering, and furnishing the proposed new Club-house, No. 1317 Spruce Street; and also an estimate of the probable expenses and estimated revenue under the proposed increase in Club dues.

Regular Meeting, October 19, 1907.—Present: President Quimby; Vice-Presidents Dallett and Devereux; Directors Dodge, Easby, Head, Loomis, and Perrot; and the Treasurer; Mr. Head acting as Secretary pro tem.

The report of the Treasurer for the month of September was read and accepted as follows:

Balance, August 31, 1907,	$4248.95
September Receipts,	580.00
	$4828.95
September Disbursements,	346.52
Balance, September 30, 1907,	$4482.43

The Treasurer also presented an approximate estimate of the probable receipts and expenditures up to the end of the current year.

It was moved and carried that the Club supply J. R. Bibbins with reprints of his paper without extra charge.

It was moved and carried that the Secretary be directed to ask Mr. Henry G. Morris to reconsider his resignation.

The Treasurer was directed to sell the Five Hundred Dollar United States War Bond, and transfer the money so received to the Club's active account; also to transfer $950 from the Colonial Trust Company and $1050 from the West End Trust Company to the Club's active account.

Special Meeting, October 23, 1907.—Present: President Quimby; Vice-Presidents Dallett and Devereux; Directors Dodge, Loomis, Head, and Perrot; and the Treasurer; Mr. Head acting as Secretary pro tem.

The business of the meeting was to prepare a statement to be issued to the members with the ballots to be voted on November 2d on the changes in the By-Laws, and to take whatever action might be necessary to complete the purchase of the new Club-house.

Special Meeting, November 2, 1907.—Present: President Quimby; Vice-President Dallett; Directors Dodge, Easby, Head, Loomis, and Perrot; the Secretary and the Treasurer.

It was moved and carried that Ballinger & Perrot be selected as architects for the alteration of the new Club-house.

It was moved and carried that the President, Treasurer, and Secretary be authorized to carry out the resolution passed by the Club on October 19th, completing the purchase of the Club-house, No. 1317 Spruce Street.

It was moved and carried that a lawyer, Mr. Francis G. Taylor, be consulted regarding the form of all papers to complete the purchase, to arrange for trustees on the second mortgage bonds, and to formulate all other necessary legal details.

It was moved and carried that the House Committee be appointed a Building Committee to supervise the alterations and furnishing of the new Club-house, with authority to act.

ADDITIONS TO THE GENERAL LIBRARY.

From Metropolitan Water and Sewerage Board.

Sixth Annual Report, 1906.

From Ohio Engineering Society.

List of Members for 1907.

From The Yale Club of New York City.

Annual of the Yale Club of New York City, 1907.

From Board of Water-supply of the City of New York.

Contract No. 3 for Construction of Main Dams for the Ashokan Reservoir.

Contract No. 4 for Construction of a Field Office Building, for Division and Section Engineers.

Contract No. 5 for Construction of a Portion of an Intercepting Sewer in the City of Kingston, N. Y.

From Delaware County Institute of Science.

Proceedings of the Delaware Co. Institute of Science, April and October, 1907.

From University of Pennsylvania.

Proceedings of Commencement, June 19, 1907.

From Government Geologist.

Annual Progress Report of the Geological Survey of Western Australia for the year 1906.

Bulletin No. 26, Miscellaneous Reports.

From City Engineer of Toronto.

Annual Report of the City Engineer of Toronto, 1906.

From Sewerage and Water Board of New Orleans.

Fifteenth Semi-Annual Report.

From The Board of Water Commissioners, Wilmington, Del.

Thirty-seventh Annual Report.

From American Mining Congress.

Papers and Addresses of the Ninth Annual Session.

From State Geologist.

Annual Report of the State Geologist of the Geological Survey of New Jersey, 1906.

From Emil L. Nuebling.

Forty-second Annual Report of the Board of Water Commissioners, Reading, Pa., 1906 and 1907.